Ground Gain

Between Theory & Practice

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Agenda

- Introduction
- The Theory
- Practical aspects – Measurements
- Case Studies
- Conclusion

ON4KHG - Ham-radio "CV" (1/2)

- Born on January 30th, 1971.
- 1983-1986 : listening to international SW Broadcast & C.B.
- 1987 (age 16) : succeeded ham examination, got call-sign ON1KHN (VHF only, no CW).
- 1988 : succeeded CW examination, got call-sign ON4KHG (all bands & modes). Interest in VHF weak signals.
- 1989 : firsts MS (SSB & HSCW) QSO's.
- 1990 : beside 2m, a bit of 6m activity.
- 1994 : first CW EME QSO with W5UN, with 100W & single 17-el F9FT.
- 1999 : launch of first internet home page (http://www.on4khg.be).
- Up to 2000 : despite very poor VHF QTH (bad take-off), lots of 2m terrestrial QSO's (320+ grids worked). Contesting at top of coal heaps (2m, 23cm & 3cm).
- 2002 : moved. Better VHF QTH. Still only single yagi and 100W on 2m.

ON4KHG - Ham-radio “CV” (2/2)

- 2003 : upgraded to 300W on 2m (homebrew SSPA with MRF141G).
- 1999-2003 : UBA VHF Contest Manager.
- 2007 : got curious & interested in digital EME…and Ground Gain. Article about 2m SSPA published in DUBUS. First experiments with SDR.
- 2009 : one of the few ON “starters” on 4m (actually then 69.950 MHz).
- 2011 : ON 2m tropo distance record (2991 km with CU). Article about Ground Gain published in DUBUS.
- 1987-date :
  - Few Firsts on 6, 4 & 2m.
  - No more than 300W & 14 dBd antenna gain on 2m (no elevation) :
    - 13 CW EME initials
    - 271 Digital EME initials
    - 98 DXCC’s
  - Lots of homebrewed equipment, papers written and presentations in local clubs.
  - 20000+ QSO’s (95% on 2m).

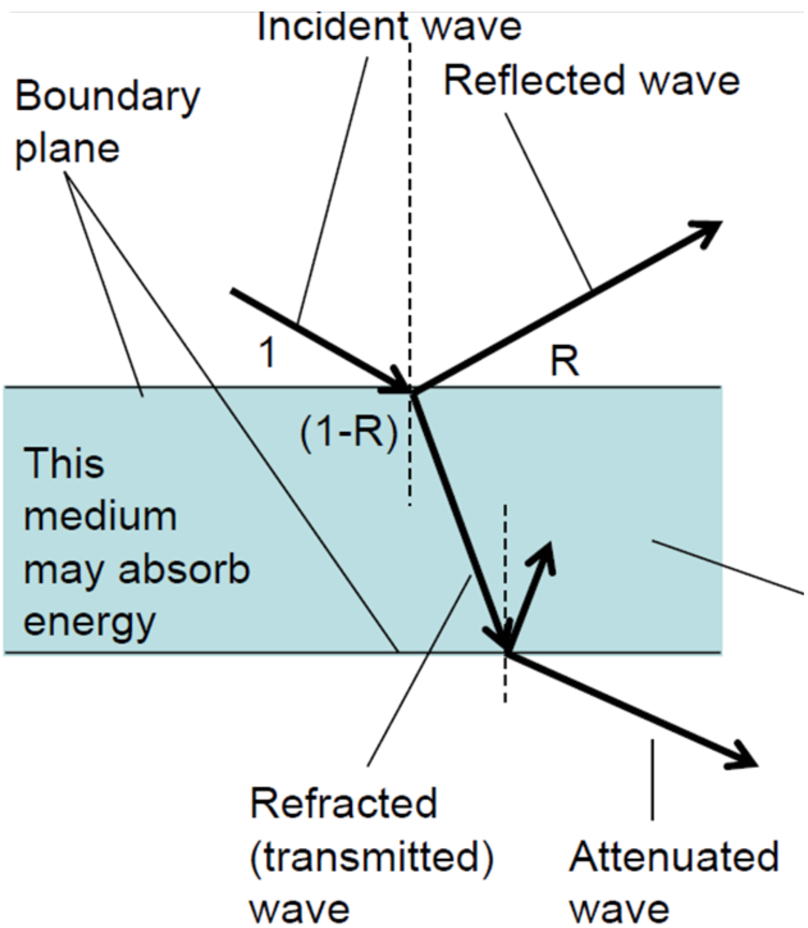
Ground Gain, what is it ?

- For antenna systems located above a **real ground** (≠ free space).
- Far away from the antenna, the direct wave and the ground reflected waves :
  - Are **in phase** at certain elevation angles ➔ they add ➔ constructive interference ➔ **up to 6 dB gain**.
  - Are **out of phase** at other elevation angles ➔ they subtract ➔ destructive interference ➔ **infinite loss**.
- Hence, the far field radiation pattern in the elevation plane is **altered** by the ground.
- Effects differ according to the **polarization**.
- Cost-less gain but needs careful siting.
- Of great help for stations without elevation for **EME** (but not only).

Goals

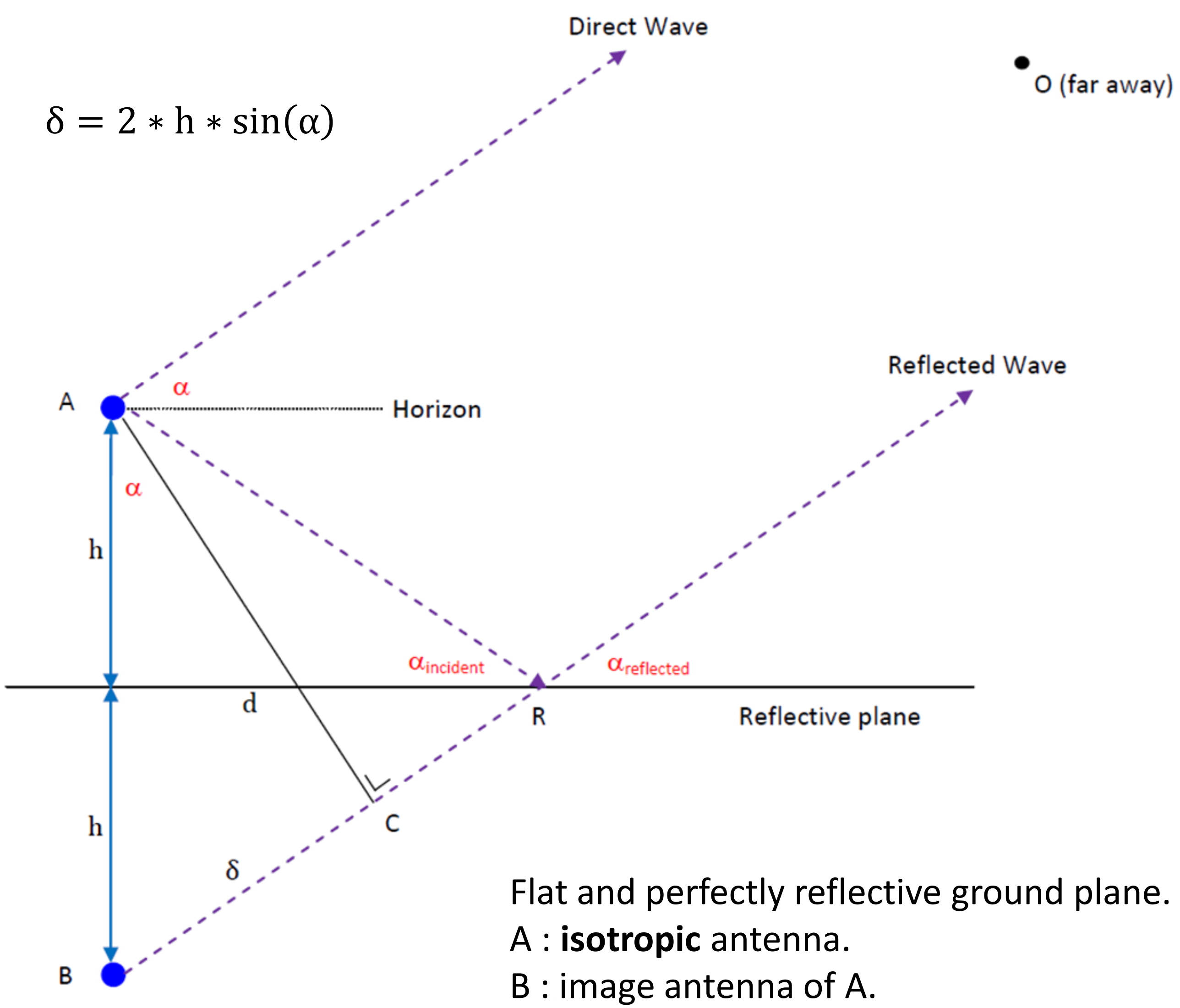
- Ground Gain in the ham literature so far :
  - "*QRP EME on 144 MHz*", by Ray Soifer W2RS in QST Feb. 1989 & Oct. 1990.
  - Articles of Palle, OZ1RH :
    - Lecture at Weinheim UKW-Tagung 1995 : "*Troposcatter at 50 MHz – 700km QSO's anytime*"
    - Abstract of EME 2002 Conference in Prague : "*Ground gain and radiation angle at VHF*"
- These papers "opened the way" and provided good theoretical basis.
- The goals here are :
  - **Remind** and broaden a bit the theoretical aspects.
  - **Experimentally assess** the Ground Gain lobes magnitude and geometry.
  - **Correlate** experiment results with real-life EME traffic.
- The focus throughout this presentation is on **144 MHz** (though principles are applicable to other frequencies).
- This presentation follows an article [1] published in DUBUS 3/2011.

Reflection



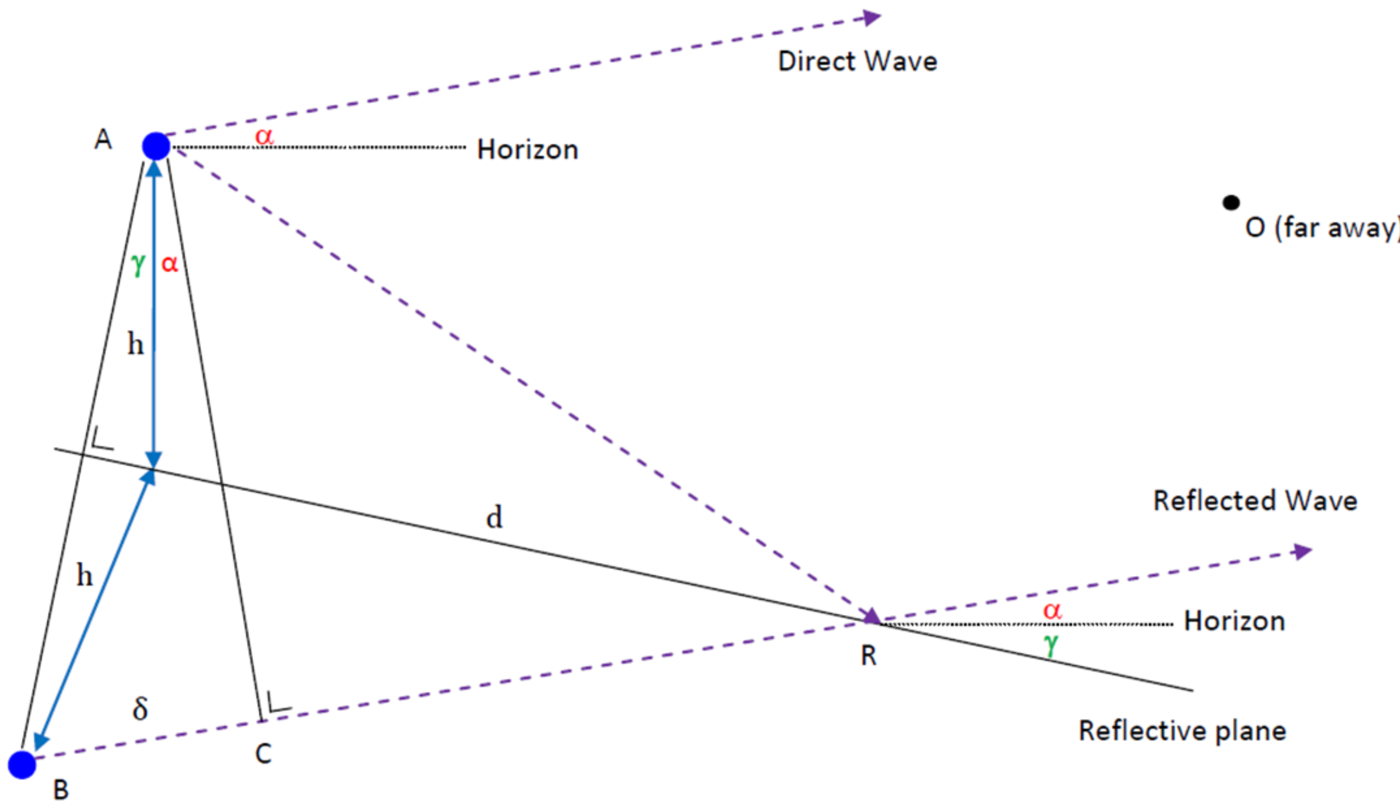
- It is the **abrupt change** in direction of a wave front at the interface between **two dissimilar media**, so that the wave front returns into the medium from which it is originated.
- Reflecting object is **large** compared to the wavelength.
- The incident angle **equals** the reflected angle (Snell-Descartes law).
- Changes the **magnitude** and **phase** (depending on the polarization) of the reflected wave.

The big "Picture" – Flat ground



Flat and perfectly reflective ground plane.
A : **isotropic** antenna.
B : image antenna of A.

The big "Picture" – Tilted ground



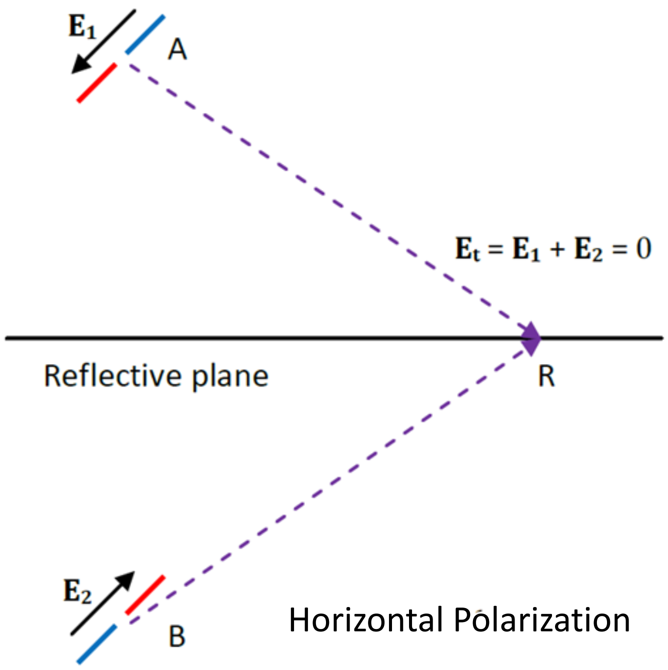
Flat and perfectly reflective ground plane.
A : isotropic antenna.
B : image antenna of A.

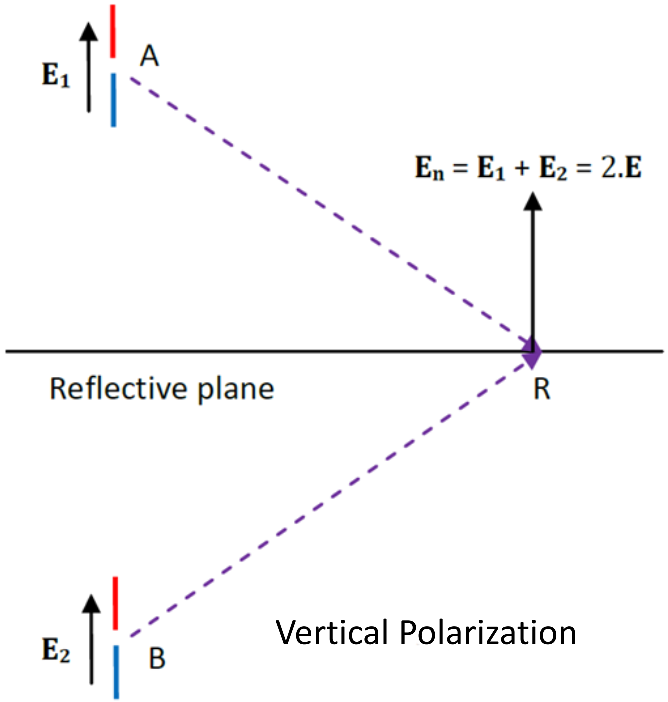
$$\delta = 2 * h * \cos(\alpha) * \sin(\alpha - \gamma)$$

Boundary conditions

"Boundary" = plane which separates two media.
Assume the boundary to be a perfectly reflective/conducting surface.
$\mathbf{E_t}$: tangential (horizontal) component of the electrical field.
$\mathbf{E_n}$: normal (perpendicular) component of the electrical field.

$$\mathbf{E_t} = 0$$
$$\mathbf{E_n} = \sum \mathbf{E_i}$$





The **horizontal polarization** suffers a **180° phase shift** when reflecting on a **perfect ground.**

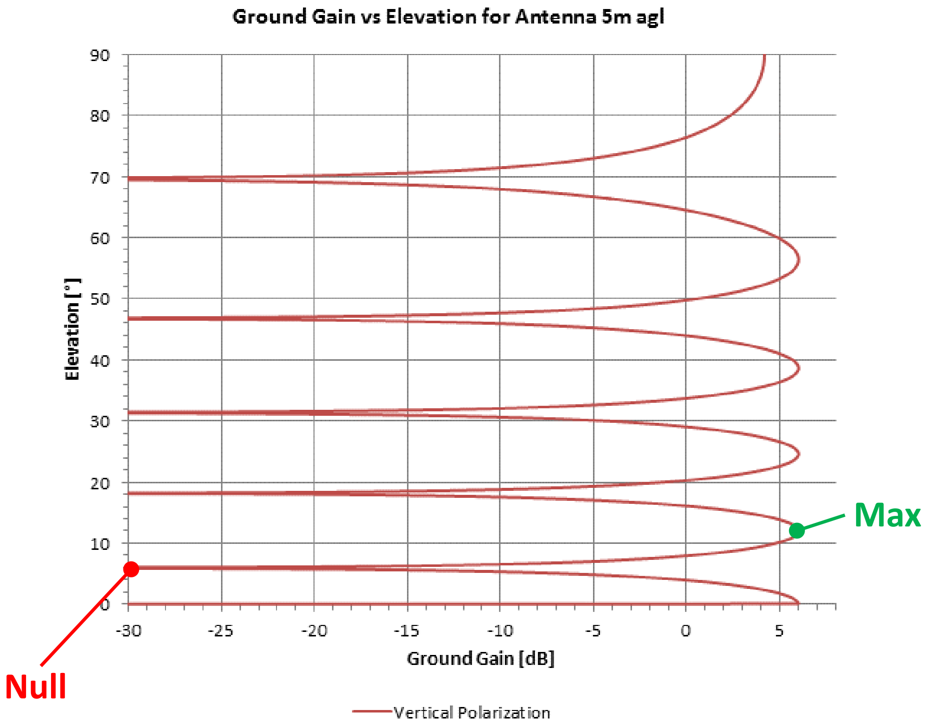
Vertical vs Horizontal Polarizations (1/2)

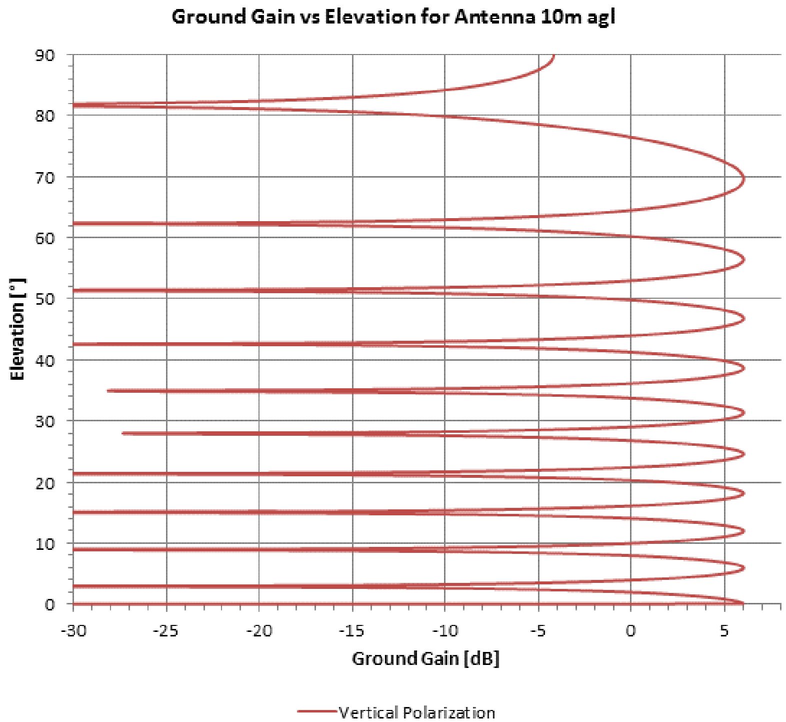
	Vertical Pol.	**Horizontal Pol.**
Direct wave	Electrical field **E**	
Reflected wave	**E** phase shifted by δ (due to excess path length)	**E** phase shifted by δ (excess path length) + 180° (reflection)
At "O" (far away), **E** is **doubled** (constructive interference) when : ➔ "**Max**" in antenna elev. pattern	δ = n*360°	(δ+180°) = n*360° Or δ = (2*n-1)*180°
At "O" (far away), **E** is **null** (destructive interference) when : ➔ "**Null**" in antenna elev. pattern	δ = (2*n+1)*180°	(δ+180°) = (2*n+1)*180° Or δ = n*360°

E doubled ➔ + **6** dB (this is the Ground Gain) (*)
E null ➔ - ∞ dB

(*) : $GG = 10*\log(|E|^2)$

Antenna elev. pattern in Vert. Pol. (perfect ground)

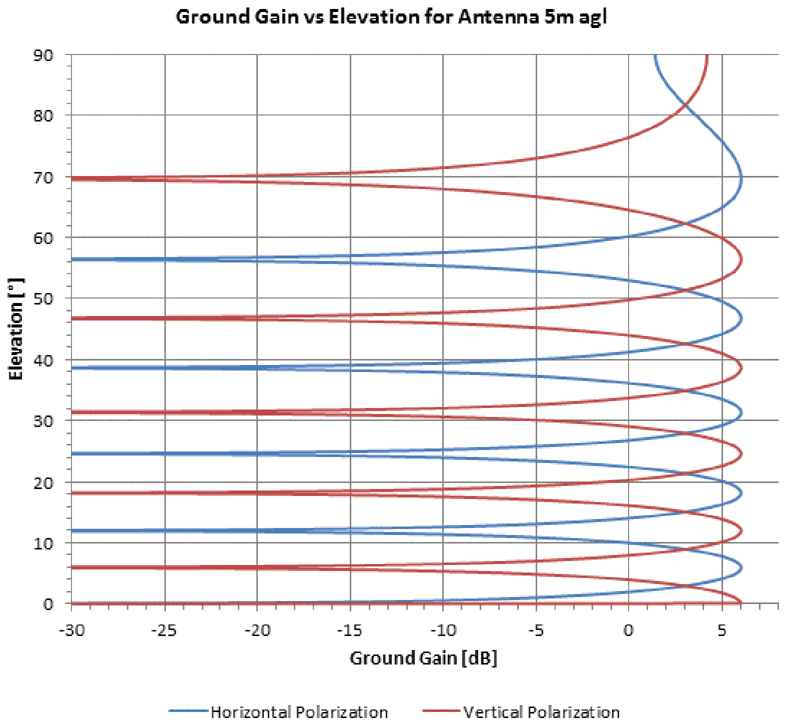


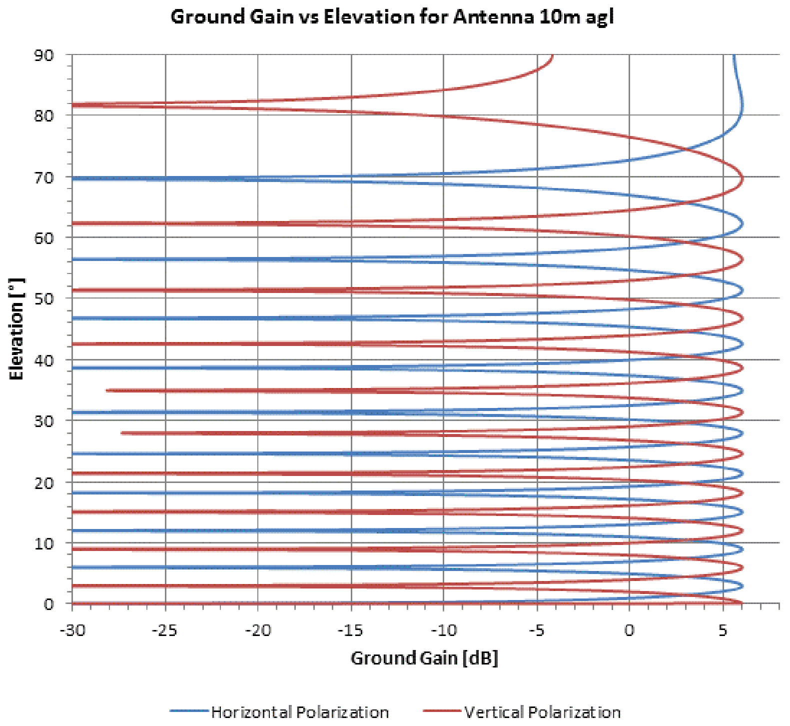


- The **higher** the antenna, the **more the amount** of max. & nulls.
- The **higher** the antenna, the **narrower** the lobes in the elevation pattern.
- First lobe has very **low radiation angle**.

Graphs drawn thanks to a home-made tool under Excel 2007 © [2]

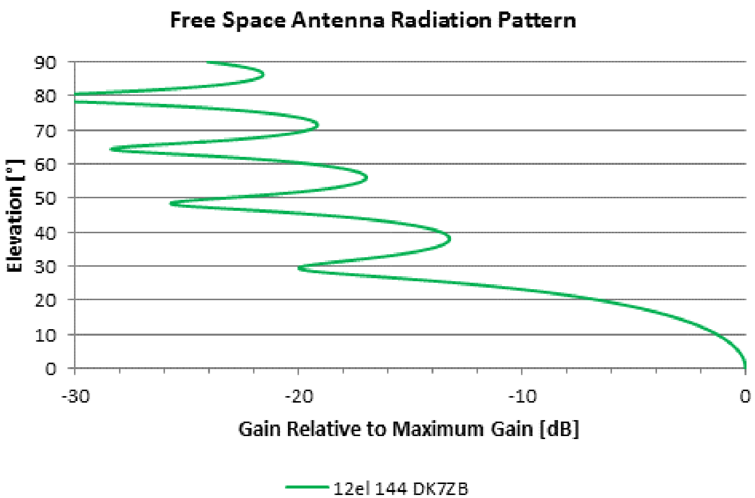
Antenna elev. pattern in Hor. Pol. (perfect ground)





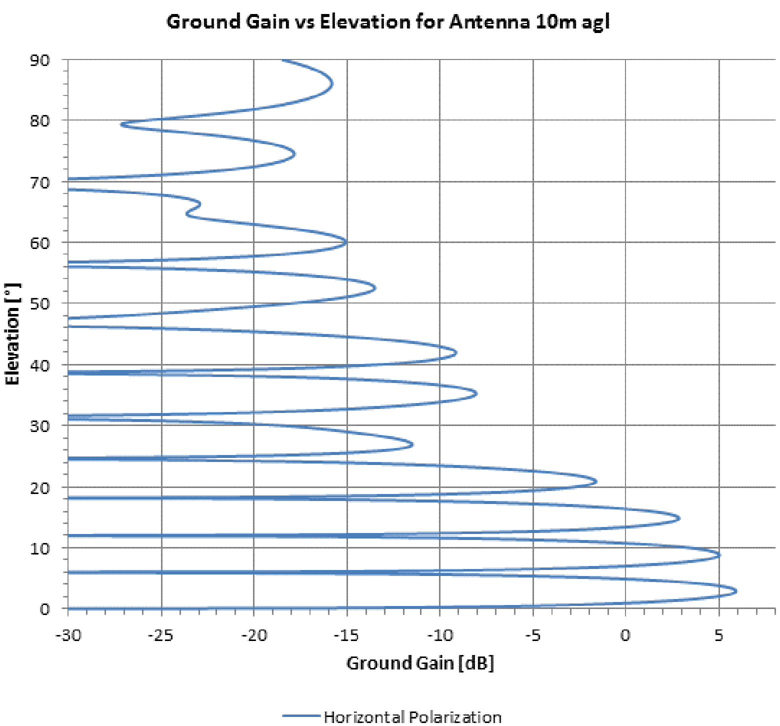
- **Similar shape** of elevation pattern for **both** vert. & hor. pol. in function of antenna height.
- **<u>BUT</u>** a **max.** in **vert.** pol. corresponds to a **null** in **hor.** pol. and vice-versa.

And with a real antenna over the same perfect ground ?

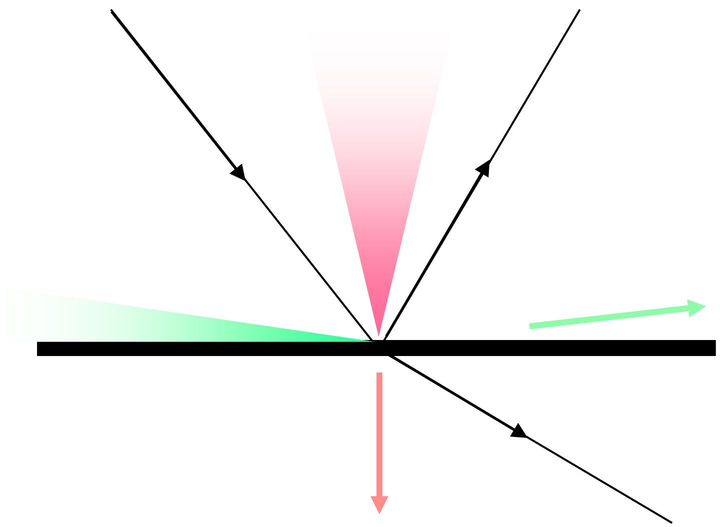


12-el 4λ DK7ZB taken as example.

Multiply (or add if in dB-scale) the **free space** antenna radiation pattern (in elevation) with the **ground altered** elevation pattern of the “isotropic” antenna (see previous two slides).

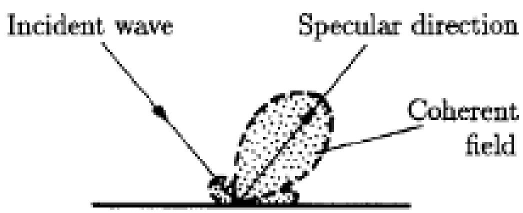


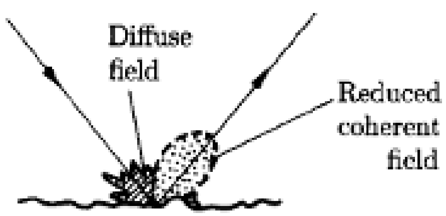
What about over a real ground plane ? (1/2)

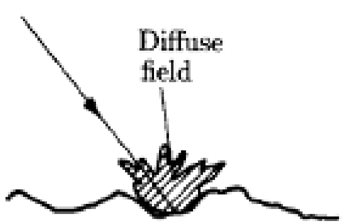


- In the real world, the ground is **never** a perfect conductor !
- **Steep angles transmit** the most.
- **Shallow grazing angles reflects** the most.
- Look perpendicularly at a window, you see through it.
- Look obliquely at a window, it acts like a mirror, though **it is not** a mirror.

What about over a real ground plane ? (2/2)







- A “good” or “**specular**” reflection is achieved if :
  - Change or **discontinuity** between propagation medium and reflective surface is as **sharp** as possible.
  - The greater the **change in dielectric** constant.
  - **Irregularities** on the reflective surface **small** as compared with the wavelength.
  - Very **low incidence angle**, shallow grazing being the best of all.
- If conditions above not fully met, the reflection may be **lossy**.

Dielectric constants of real ground

- The **reflective properties** of a real ground are governed by its **dielectric constants** :
  - The relative **permittivity** ε_r [dimensionless].
  - The **conductivity** σ [S/m].
- Both are embedded in the **complex permittivity** :

$$\varepsilon' = \frac{\varepsilon}{\varepsilon_0} - j * \left(\frac{\sigma}{2 * \pi * f * \varepsilon_0}\right) = \varepsilon_r - j * \left(\frac{\sigma}{2 * \pi * f * \varepsilon_0}\right)$$

ε : absolute permittivity [F/m].
ε_0 : permittivity of the vacuum, $8.854*10^{-12}$ [F/m].
f : frequency [Hz].

Dielectric constants of some common soil types

	Conductivity σ [S/m]	Permittivity ε_r [ ]
Poor	0.0010	4.5
Moderate	0.0030	4.0
Average	0.0075	12.5
Good	0.0150	20.0
Dry, Sandy, Flat (Coastal Land)	0.0020	10.0
Pastoral Hills, Rich Soil	0.0065	17.0
Pastoral Medium Hills and Forestation	0.0050	13.0
Fertile Land	0.0020	10.0
Rich Agricultural Land (Low Hills)	0.0100	15.0
Rocky Land, Steep Hills	0.0020	12.5
Marshy Land, Densely Wooded	0.0075	12.0
Mountainous/Hilly (to about 1000 m)	0.0080	12.0
Highly Moist Ground	0.0010	5.0
City Industrial Area of Average Attenuation	0.0125	30.0
City Industrial Area	0.0010	5.0
Fresh Water	0.0001	3.0
Sea Water	0.0060	81.0
Sea Ice	4.5000	81.0
Polar Ice	0.0010	4.0

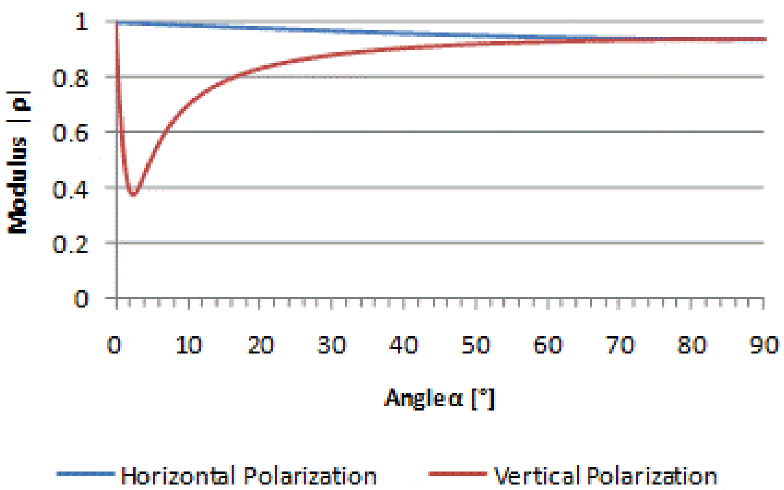
Ground reflection coefficients (1/3)

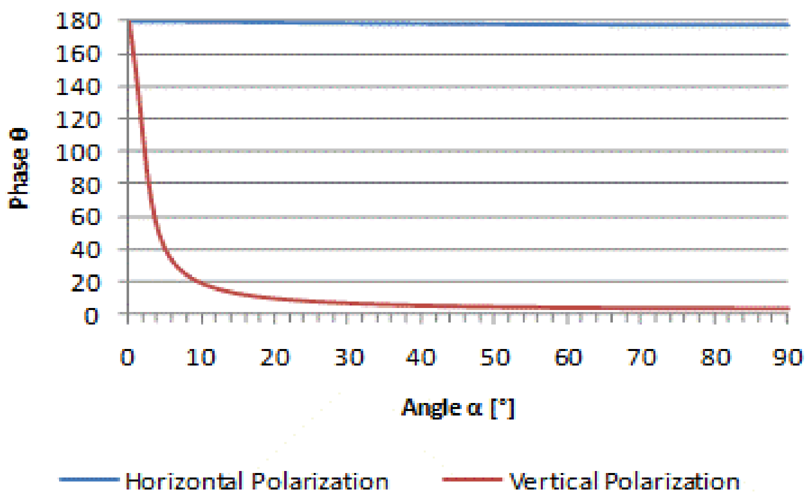
- Real grounds affect **reflection** of waves through the reflection **coefficients** ρ, dependant of the **polarization** :
  - For vertical polarization : $\boldsymbol{\rho_v} = \frac{\varepsilon' * \sin(\alpha) - \sqrt{\varepsilon' - \cos^2(\alpha)}}{\varepsilon' * \sin(\alpha) + \sqrt{\varepsilon' - \cos^2(\alpha)}}$
  - For horizontal polarization : $\boldsymbol{\rho_h} = \frac{\sin(\alpha) - \sqrt{\varepsilon' - \cos^2(\alpha)}}{\sin(\alpha) + \sqrt{\varepsilon' - \cos^2(\alpha)}}$

- These are frequency dependant and complex numbers :
  - **Modulus** (magnitude).
  - **Phase**.

Ground reflection coefficients (2/3)

Plotting the modulus |ρ| and phase θ of the reflection coefficients for vertical and horizontal polarizations and for **<u>the sea water</u>** taken as an example gives :

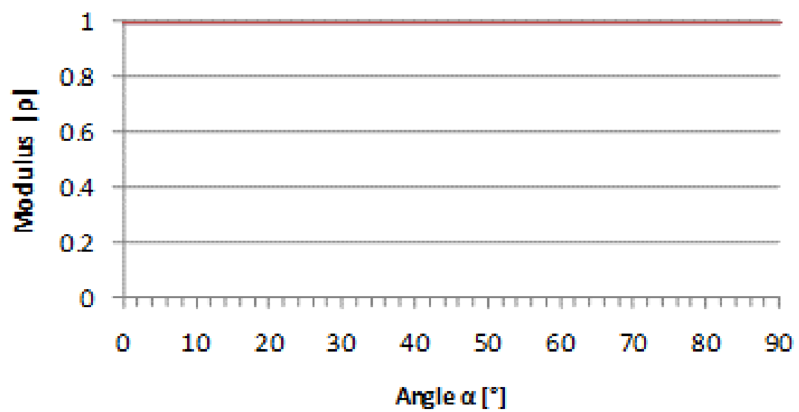


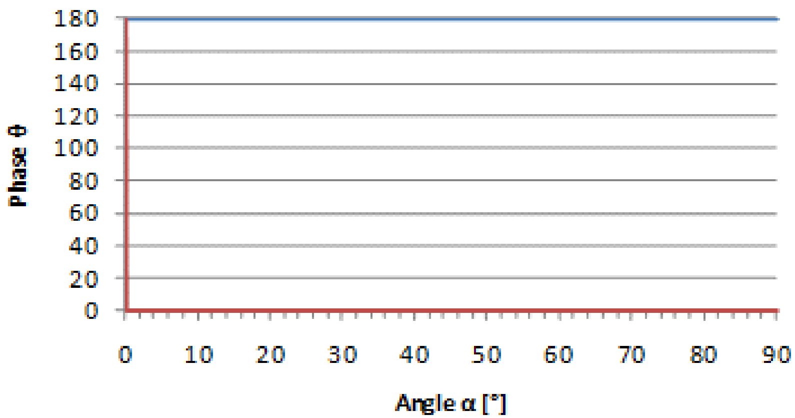


<u>Rem :</u> Though, sea water is not a perfect conductor, it is **close** to and one finds back the 180° phase shift typical to horizontal polarization over a perfect conductor (see graph on the right).

Ground reflection coefficients (3/3)

Plotting the modulus $|\rho|$ and phase θ of the reflection coefficients for vertical and horizontal polarizations and for **an ideal perfect ground** gives :





Rem : The modulus of the reflection coefficient equals to 1, meaning the reflection is **loss-less**. The phase shift in vertical polarization (red line) equals to 0°, while it amounts to 180° for horizontal polarization (blue line).

Magnitude of the electrical field

- Far away from the antenna, the **electrical field** (∑ direct & reflected waves) is given by :

$$\mathbf{E} = \mathbf{E_{direct}} + \mathbf{E_{reflected}} = \left(1 + |\rho_{h,v}| * \cos(\Delta)\right) + j * |\rho_{h,v}| * \sin(\Delta)$$

- The **magnitude** of the electrical field is then :

$$|E| = \sqrt{1 + 2 * |\rho_{h,v}| * \cos(\Delta) + |\rho_{h,v}|^2}$$

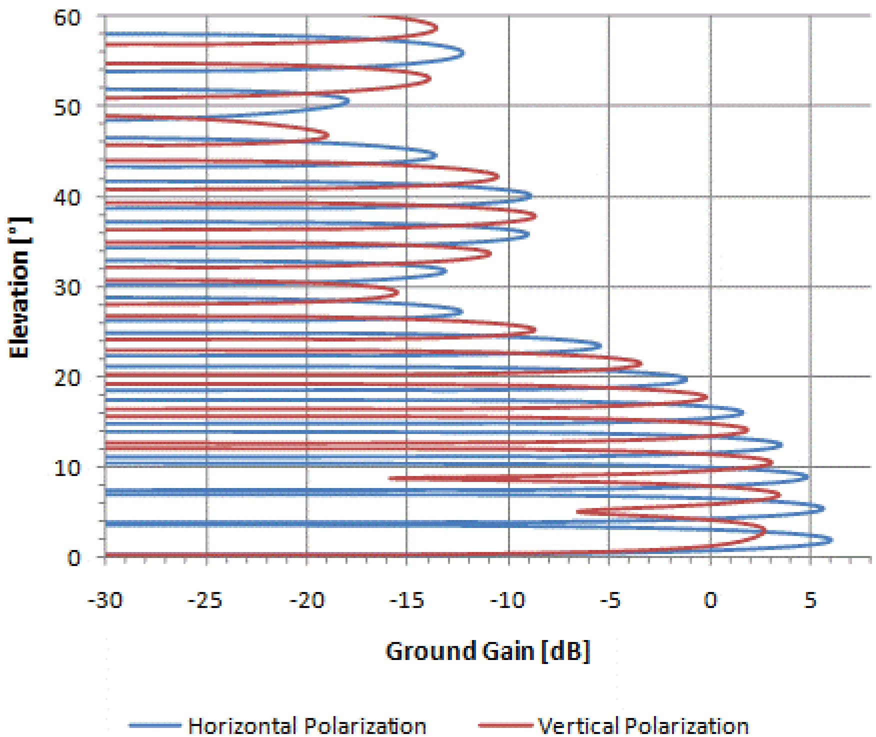
- And the magnitude of the elevated lobes is then :

$$GG = 10 * \log(|E|^2) = 10 * \log\left(1 + 2 * |\rho_{h,v}| * \cos(\Delta) + |\rho_{h,v}|^2\right)$$

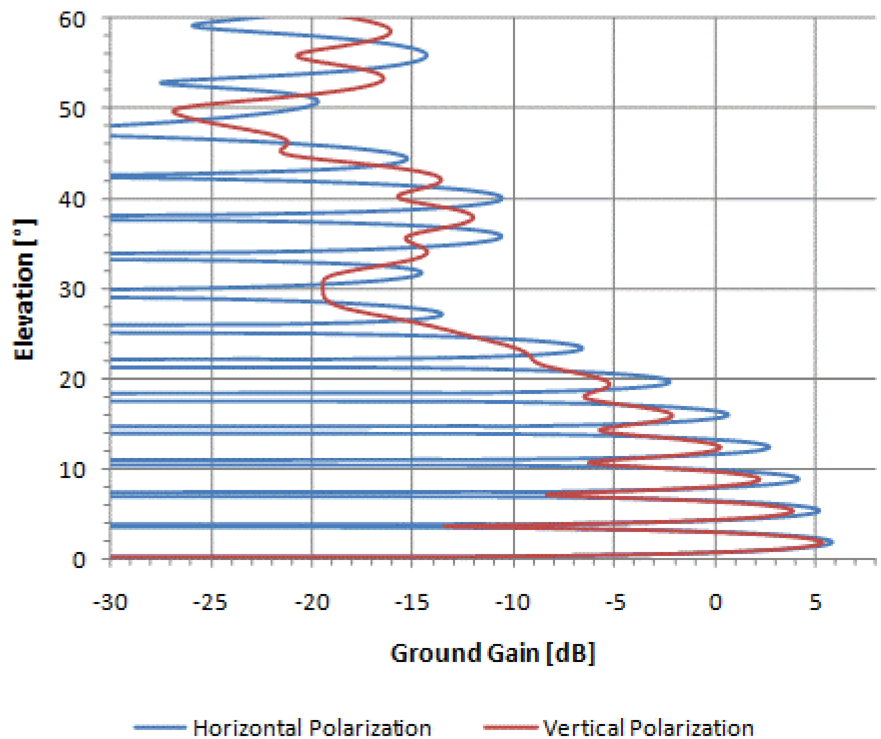
- Where the total **phase shift** is : $\Delta = \delta + \theta_{v,h}$
  - δ is due to the **extra path length** between the direct and ground reflected wave fronts.
  - $\theta_{v,h}$ is the **phase** of the reflection coefficients for vertical or horizontal polarizations.

Magnitude & geometry of the elev. lobes (over a real ground)

For the same antenna 12-el DK7ZB as before, at 17.3m agl, we plot **GG** in function of the **elevation angle α** :



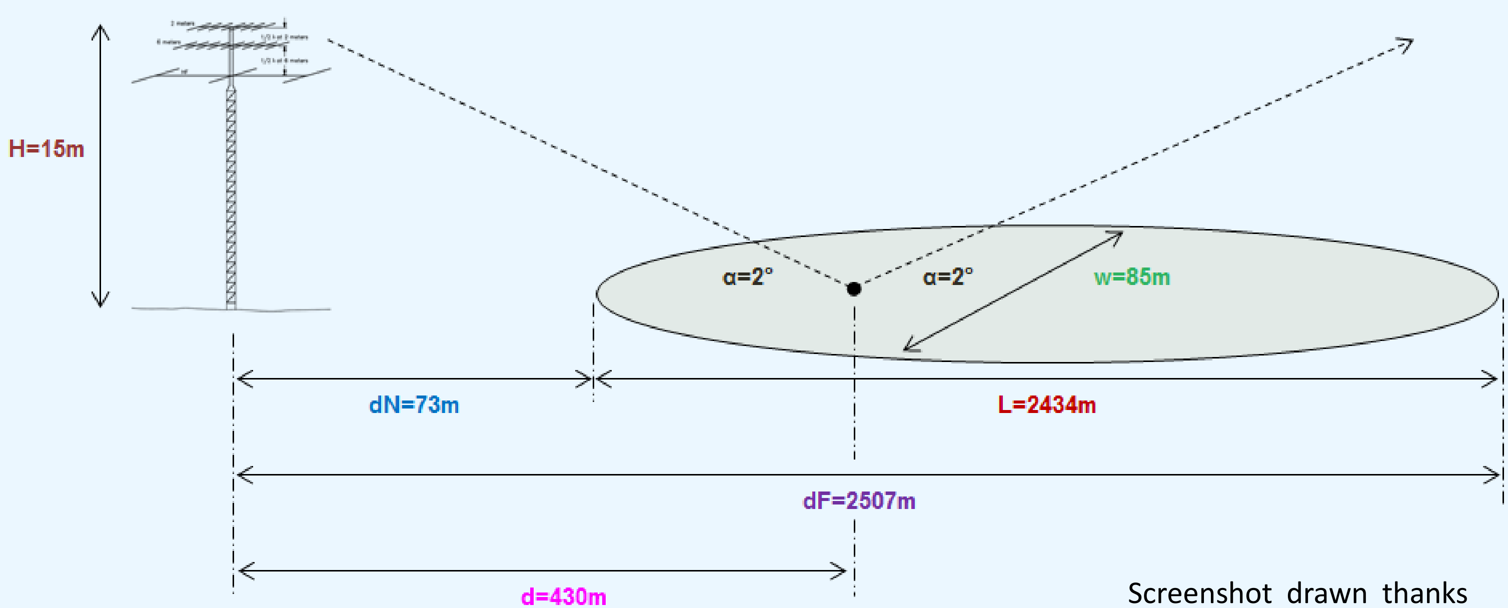
Sea Water



"Poor" ground

How far from the antenna do the lobes build ? (1/2)

Fresnel Zone Geometry for the 1st Elevation Lobe

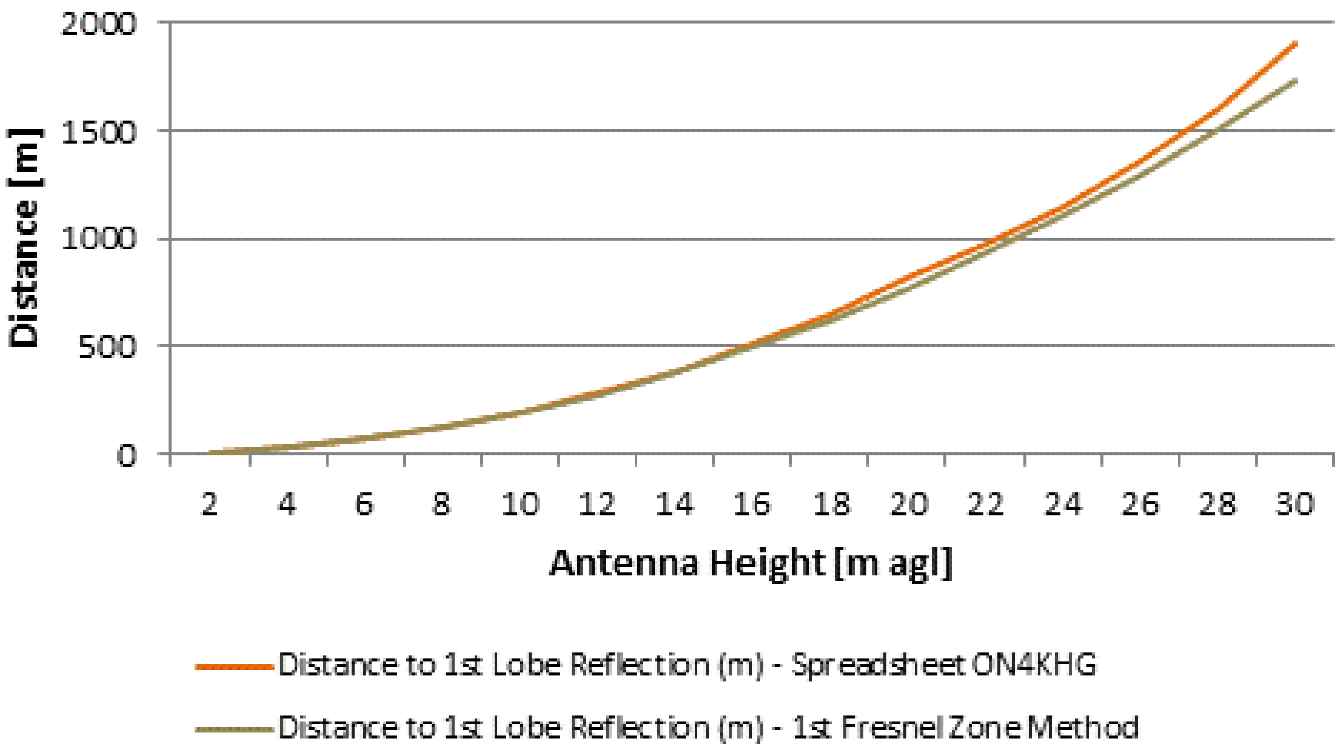


Screenshot drawn thanks to a home-made tool under MS Excel 2007 [1]

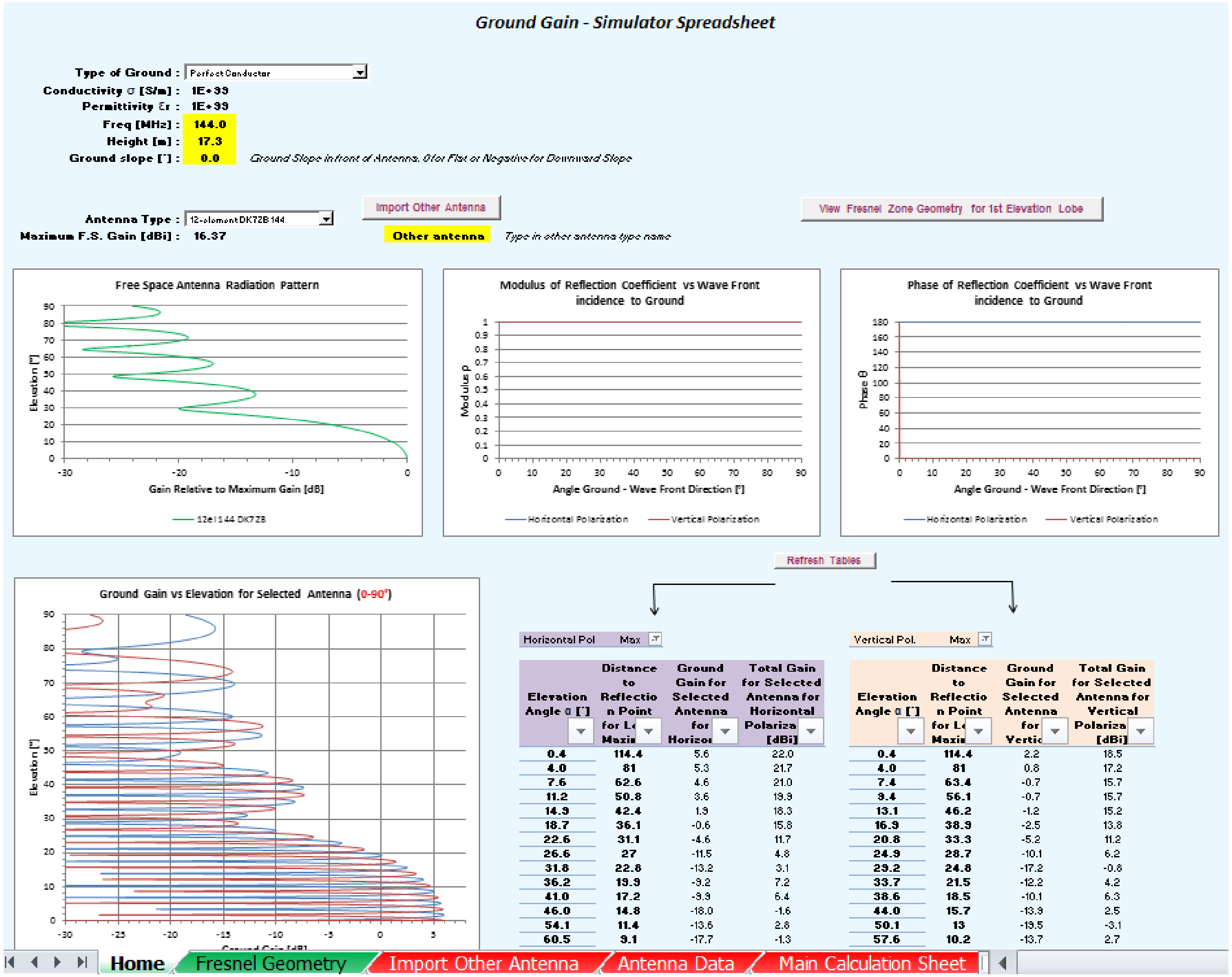
Antenna height H [m] :	15.0	
Frequency [MHz] :	144.0	
λ [m] :	2.1	
α [°] :	2.0	*Elevation angle of the first lobe (Hor. Polar.)*
d [m] :	430	*Distance from antenna where the maximum of the first lobe builds*
dN [m] :	73	*Closest distance from antenna as from which first ground lobe builds*
dF [m] :	2507	*Furthest distance from antenna up to which first ground lobe builds*
w [m] :	85	*"Width" of the Fresnel Ellipsoid*
L [m] :	2434	*"Length" of the Fresnel Ellipsoid*

How far from the antenna do the lobes build ? (2/2)

Distance between antenna and where the **maximum** of the 1st elevation lobe builds, in function of the **antenna height** :



Model and simulate your Ground Gain



Elevation Angle α [°]	Distance to Reflectio n Point for L… Maxi…	Ground Gain for Selected Antenna for Horizon…	Total Gain for Selected Antenna for Horizontal Polariza… [dBi]
0.4	114.4	5.6	22.0
4.0	81	5.3	21.7
7.6	62.6	4.6	21.0
11.2	50.8	3.6	19.9
14.9	42.4	1.9	18.3
18.7	36.1	-0.6	15.8
22.6	31.1	-4.6	11.7
26.6	27	-11.5	4.8
31.8	22.8	-13.2	3.1
36.2	19.9	-9.2	7.2
41.0	17.2	-9.9	6.4
46.0	14.8	-18.0	-1.6
54.1	11.4	-13.6	2.8
60.5	9.1	-17.7	-1.3

Elevation Angle α [°]	Distance to Reflectio n Point for L… Maxi…	Ground Gain for Selected Antenna for Vertic…	Total Gain for Selected Antenna for Vertical Polariza… [dBi]
0.4	114.4	2.2	18.5
4.0	81	0.8	17.2
7.4	63.4	-0.7	15.7
9.4	56.1	-0.7	15.7
13.1	46.2	-1.2	15.2
16.9	38.9	-2.5	13.8
20.8	33.3	-5.2	11.2
24.9	28.7	-10.1	6.2
29.2	24.8	-17.2	-0.8
33.7	21.5	-12.2	4.2
38.6	18.5	-10.1	6.3
44.0	15.7	-13.9	2.5
50.1	13	-19.5	-3.1
57.6	10.2	-13.7	2.7

- As far as **flat ground** is concerned, modelling is easy.
- Use the "Ground Gain Geometry and Magnitude Calculator File" (Excel 2007 ©) [2].
- To be downloaded at http://www.on4khg.be
- The outcome of many simulations has lead to the "**Conclusion of the theory**" (next 2 slides).

Conclusion of the theory (1/2)

	Vertical Polarization	Horizontal Polarization
Antenna height (1/3)	The higher the antenna, the lower the elevation angle of the first Ground Gain lobe.	The same.
Antenna height (2/3)	The higher the antenna, the more and the narrower the lobes and the nulls.	The same.
Antenna height (3/3)	The higher the antenna, the further from the antenna and the wider the surface on the ground needed for the lobes to build.	Same behavior but lobe building occurs even further away from the antenna than for vertical polarization. For highly conductive real grounds, it is twice the distance for a perfectly conductive ground.
Ground properties	Elevation angles at which Ground Gain is achieved are very dependant on the ground properties.	Ground Gain lobes always occur at the same elevation angles, no matter the ground properties.
Magnitude of the lobes (1/2)	The more Ground Gain at the elevation maxima, the deeper the nulls.	The same.
Magnitude of the lobes (2/2)	The magnitude is very dependant of the ground properties (and the pseudo-Brewster angle). For instance, sea water (highly conductive) exhibits a lower magnitude on the first lobe than in the subsequent more highly elevated lobes (but still less compared to horizontal polarization). However, for a poor ground, the difference of magnitude of the first lobe is very tight compared to the horizontal polarization (5.5 dB for vertical compared with 6 dB for horizontal), while this same difference increases for the more elevated lobes (less and less gain for vertical versus horizontal polarizations).	The magnitude of the first lobe (grazing angle) can easily reach 6 dB for any ground type (highly or poorly conductive). The magnitude of the more highly elevated lobes suffers more of the reflective properties of the ground (and the free space antenna radiation pattern too, but this is implicit), the incidence angles being less and less grazing.

Conclusion of the theory (2/2)

	Vertical Polarization	Horizontal Polarization
Sloping ground	Same behavior as above but the Ground Gain elevation angles are lower than for a flat ground (heading more towards the horizon than the sky) and the distance where the lobes build is much closer to the antenna than for a flat ground.	
Near field	Some highly elevated lobes build very close to the antenna, where the near field still prevails and hence where the radiation pattern of the antenna is not built yet. The validity of these lobes is very questionable.	
Radiation pattern	We have assumed so far that (except for the effect of the reflection coefficient on the magnitude of the reflected wave), the direct and reflected waves have the same magnitude far away from the antenna. This is true for the low elevation angle lobes, for which the reflected wave is originating from close to the maximum of the (free space) antenna radiation pattern. The high elevation lobes are made up of reflections close to the antenna and then the wave front originating from the antenna is already well attenuated by the radiation pattern of the antenna. Hence, the highly elevated lobes have actually a lower magnitude than depicted on the graphs. This is even more true for the high gain antennas (narrow radiation pattern) and/or for a sloping ground (reflections building closer from the antenna than for a flat ground).	
Frequency	This page focuses on 144 MHz but it is worthwhile to mention that given the height of a 432 MHz antenna compared to the wavelength, the lobe pattern will be made up of many narrow successive maxima and nulls. Also, because the ground irregularities must be small compared to the wavelength in order to give good specular reflections, the likelihood for useful Ground Gain on 432 MHz at most locations is not very high. In other words, the ground appears less and less "flat" (or assumed to be so) as the frequency increases. Finally, vertical polarization is more frequency dependant than horizontal polarization.	

Theory is fine but in practice ?

- **Perfect flatness** is not often applicable in reality. Terrain irregularities and clutter (building and vegetation) introduce scattering/diffraction and attenuation.
- According to the wavelength, the radio waves are more or less **penetrating into the ground** when hitting it ; while here, we have only considered a sharp boundary between the air and the ground.
- The **ground conductivity** and **permittivity** have been considered constant and uniform over the whole reflective surface. This is not the case in reality.
- We have considered a "**two rays**" model, i.e. a direct wave issued by the antenna and its reflected wave (resulting in 6 dB Ground Gain enhancement at best). In reality, there can be environments (sloping ground towards the sea, mountain valleys,...) where there can be **more than two paths** leading to constructive interference (over very narrow lobes and hence very limited time span in case of signals being received from a moving object like the moon). In these specific cases, the Ground Gain enhancement can amount to more than 6 dB (12 dB in case of four paths).

➔ Better **measure** than trying to model !

How to measure ?

Using the sun !

(Y-factor derived method)

- Emits over a very **broad** spectrum ➔ noise source.
- **Mobile** source.
- **Non**-polarized.
- SFI ("Solar Flux Index") or **RSF** ("Radio Solar Flux") noise contribution known.
- Somehow same "**geometry**" as the moon (rising in the East, setting in the West).

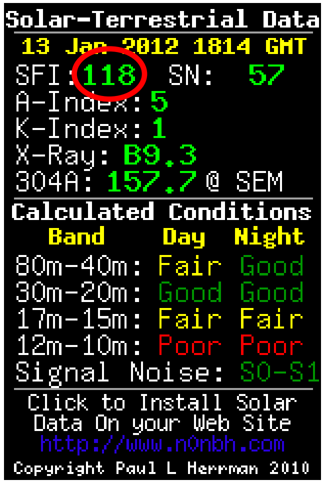
The Radio Solar Flux (RSF) (1/2)

- The US Air Force is operating a worldwide Radio **Solar Telescope** Network (RSTN), including observatory stations in :
  - Learmonth, Australia
  - San Vito, Italy
  - Sagamore Hill, Massachusetts, USA
  - Palehua, Hawaii, USA
- The Dominion Radio **Astrophysical Observatory** in Penticton, British Columbia, Canada also operates such a station.
- The **RSF** is measured at frequencies of 245, 410, 610, 1415, 2695, 2800, 4995, 8800 and 15400 MHz.
- The **Radio Solar Flux** is expressed in “sfu” (solar flux unit) : 1 sfu = 10^{-22} [W/m^2/Hz].
- The reference RSF is taken at **2800 MHz** (or at a wavelength of 10.7cm).
- It ranges from 50 (quiet sun) to 300 (very high activity) at 2800 MHz and it is closely linked to the SSN (Sun Spot Number).

The Radio Solar Flux (RSF) (2/2)

```
# Prepared by the U.S. Dept. of Commerce, NOAA, Space Weather Prediction Center
# Please send comments and suggestions to SWPC.Webmaster@noaa.gov
#  Units: 10^-22 W/m^2/Hz
#  Missing Data:  -1
#
#    Daily local noon solar radio flux values - Updated once an hour
#
```

Freq MHZ	Learmonth 0500 UTC	San Vito 1200 UTC	Sag Hill 1700 UTC	Penticton 1700 UTC	Penticton 2000 UTC	Palehua 2300 UTC	Penticton 2300 UTC
2011 Jul 12							
245	16	19	20	-1	-1	-1	-1
410	37	-1	37	-1	-1	-1	-1
610	54	-1	48	-1	-1	-1	-1
1415	81	81	85	-1	-1	-1	-1
2695	94	93	90	-1	-1	-1	-1
2800	-1	-1	-1	92	92	-1	92
4995	142	136	134	-1	-1	-1	-1
8800	255	250	260	-1	-1	-1	-1
15400	507	554	552	-1	-1	-1	-1



- There are several sources where the RSF can be found [3].
- Must be **extrapolated** from 2800 MHz down to ham frequencies.

The RSF at ham frequencies

At least two methods to calculate the **RSF** at **ham frequencies** :

- By using the "**EME Calculator**" software of Doug, VK3UM [4], which extrapolates or interpolates the RSF on the **amateur bands** above 30 MHz and up to 47 GHz, out of the daily data retrieved from the Australian Learmonth solar telescope.

- By using a **polynomial curve** [5] derived from experimental data. Since the RSF is known at 2800 MHz (RSF_{2800}), it can be calculated for the 144, 432 and 1296 MHz bands using :
  - $\mathrm{RSF}_{144} = -0.00037689 * (\mathrm{RSF}_{2800})^2 + 0.162242 * \mathrm{RSF}_{2800} - 6.02015$
  - $\mathrm{RSF}_{432} = 0.0324167 * \mathrm{RSF}_{2800} + 0.790833$
  - $\mathrm{RSF}_{1296} = 0.010417 * \mathrm{RSF}_{2800} - 0.04916$

- Comparison of the two methods :

RSF_{2800} [sfu]	EME Calculator	Polynomial curve
98	6.00	6.25
107	6.00	7.02
160	10.00	10.29
219	12.00	11.45

Description of the measurement method (1/3)

	We measure	We calculate
Step 0	-	• Antenna Noise Temperature due to the sun contribution, based on RSF ➔ derive "N_{sun}", noise power due to the sun, without ground influence (free space or elevation). • Based on when the measurement is planned, we define the azimuth range onto which to measure. Measurements at steps 2, 3 & 4 will all be performed over this same azimuth range.
Step 1 : calibration	The noise power; "$N_{reference}$", RX input terminated on 50Ω.	• "$T_{reference}$", reference noise temperature of the whole RX system (i.e. including the 50Ω load). • "T_{RX}", noise temperature of the RX alone .

n is in [W] - N is in [dBW] - T is in [K]

Description of the measurement method (2/3)

	We measure	We calculate
Step 2 : overall background noise, before influence of the sun	"N_{bgd}" ("bgd" = "background"), noise power contributions due to the background, made up of : • Earth noise, • Galactic noise, • Man-made noise, when RX input terminated on antenna.	$NR_{bgd} = N_{bgd} - N_{reference}$ ➔ noise rise in RX due to background contributions vs reference noise level ➔ derive : • "N_{bgd}", noise power, • "$T_{ant\ bgd}$", ant. noise temperature, due to the background.
Step 3 : tracking the sun over the planned azimuth range	"$NR_{measured}$", the noise rise due to the background noise (see above) + the sun noise.	• $NR_{measured} = N_{measured} - N_{bgd}$ ➔ derive "$N_{measured}$", the actual noise power due to the sun and taking into accound the ground effects. • $NR_{sun} = N_{sun} - N_{bgd}$, the theoretical sun noise rise without ground effects. NR_{sun} is calculated with $T_{ant\ sun}$, $T_{ant\ bgd}$ and T_{RX} (calculated in previous steps) as inputs.
Step 4 : overall background noise, after influence of the sun	Idem as Step 2.	Idem as Step 2.

Description of the measurement method (3/3)

- Thanks to the data collected / calculated, we have calculated the theoretical **Noise Rise** [dB] (commensurate to the background noise) that would occur on the RX system due to the **presence of the sun** in the antenna beam-width, and **without ground effects** (free space) :

$$NR_{sun} = N_{sun} - N_{bgd} = 10 * \log\left(\frac{n_{sun}}{n_{bgd}}\right) = 10 * \log\left(\frac{T_{ant\ sun} + T_{ant\ bgd} + T_{RX}}{T_{ant\ bgd} + T_{RX}}\right)$$

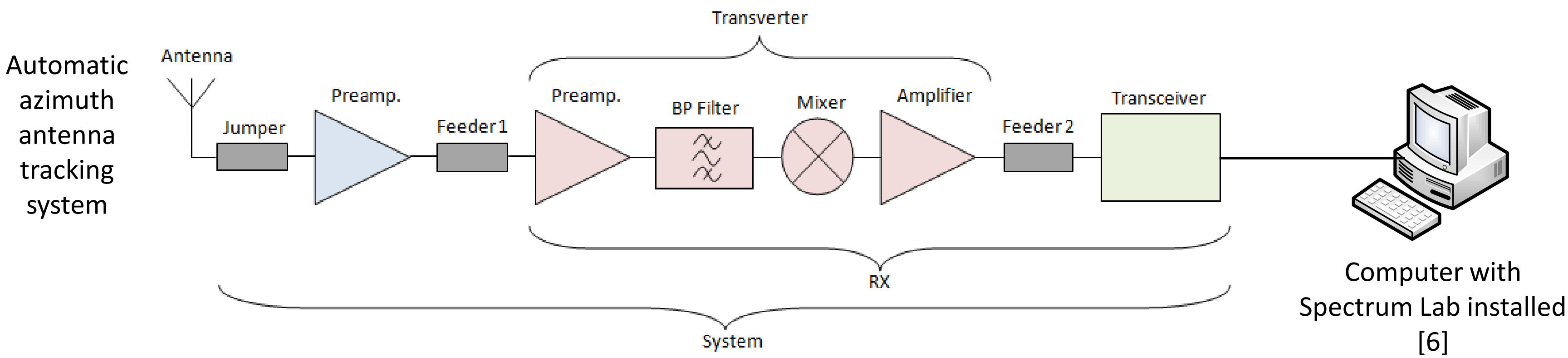
- We have measured the actual **Noise Rise** [dB] (commensurate to the background noise) on the RX system due to the **presence of the sun** in the antenna beam-width, and **with ground effects** (antenna without elevation) :

$$NR_{measured}$$

- The magnitude of the **Ground Gain** [dB] is :

$$GG = NR_{sun} - NR_{measured}$$

Measurement setup – Overall (1/2)



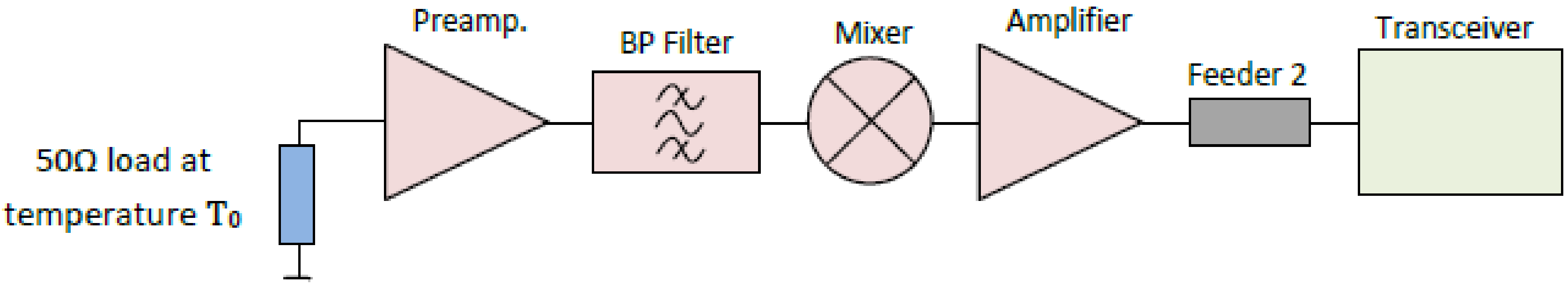
	Antenna	*Jumper*	*Preamp. (External)*	*Feeder 1*	*Preamp. (Transverter)*	*Band-Pass Filter*	*Mixer*	*(Post-mixer) Amplifier*	*Feeder 2*	*Transceiver*
Gain G [dB(i)]	G_{ant}: 16.30	G_1: -0.10	G_2: -0.10	G_3 : -0.80	G_4 : 22.00	G_5 : -2.00	G_6 : -7.00	G_7 : 9.00	G_8 : -4.00	
Gain g [ ]	42.66	g_1 : 0.98	g_2 : 0.98	g_3 : 0.83	g_4 : 158.49	g_5 : 0.63	g_6 : 0.20	g_7 : 7.94	g_8 : 0.40	
Noise Figure NF [dB]		NF_1 : 0.10	NF_2 : 0.10	NF_3 : 0.80	NF_4 : 0.40	NF_5 : 2.00	NF_6 : 7.00	NF_7 : 2.50	NF_8 : 4.00	NF_9 : 6.00
Noise Factor f [ ]		f_1 : 1.02	f_2 : 1.02	f_3 : 1.20	f_4 : 1.10	f_5 : 1.58	f_6 : 5.01	f_7 : 1.78	f_8 : 2.51	f_9 : 3.98
Noise Temp. T [K]	See sect. 5.4.	T_1 : 6.75	T_2 : 6.75	T_3 : 58.66	T_4 : 27.98	T_5 : 169.62	T_6 : 1163.4	T_7 : 225.7	T_8 : 438.45	T_9 : 864.51
Purpose of the stage		The coaxial section (that allows antenna rotation) between the antenna radiating element and preamp. or junction with feeder	Preamp. set in **by-pass mode** to ease calculations. So, the **insertion loss** is considered here	The coaxial section between the preamp. or junction with jumper and the Transverter (or Transceiver) input	First RX stage of the Transverter (or Transceiver)				The coaxial section between the Transverter output and the IF Transceiver	

Measurement setup – Overall (2/2)

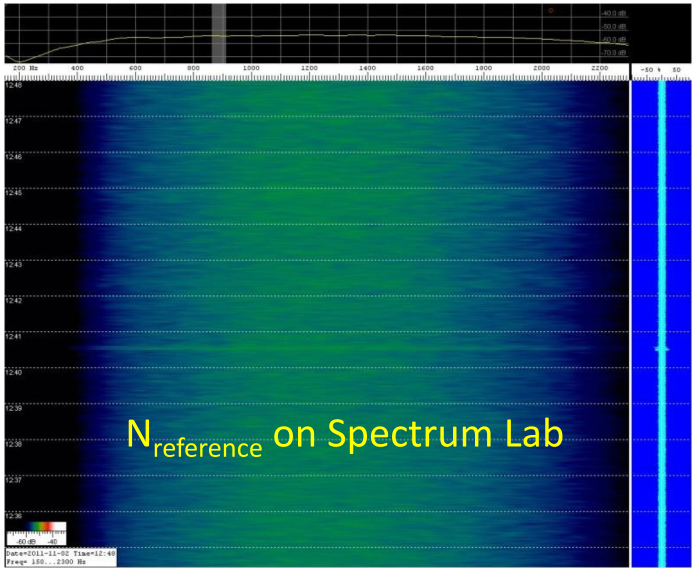
The following precautions must be observed to ensure the most accurate measurements possible :

- Transceiver **AGC** (Automatic Gain Control) set to **OFF**.
- Whole receiving chain (RX and soundcard) assumed to be **linear** (and confirmed by repeating the same measurement at higher and lower signal levels).
- Transceiver **Noise Blanker** (NB) set to **ON**. The white noise to be measured is normally not altered by the NB, while the pulse noises (disturbing the measurement) will be suppressed (but again this assumption must be verified).
- A **clear frequency**, not subject to disturbances (QRM).
- The whole station and computer **powered ON** at least **12 hours before** performing the measurement, so that the whole setup is stable and at temperature during the measurement.
- **Good weather** with no wind or rain to avoid static noise.
- Low A and K indexes (**low sun activity**).

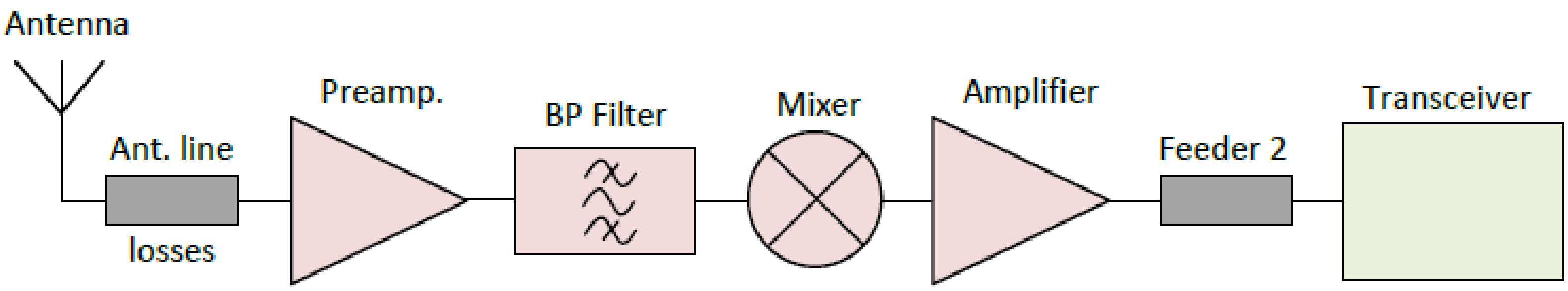
Step 1 : calibration



- RX input terminated on **50Ω**.
- Measurement of the **reference noise power** on Spectrum Lab, "$N_{reference}$".
- The noise power is **averaged** over 10 sec and sampled every 10 sec.
- Measurement bandwidth around **2 kHz**.

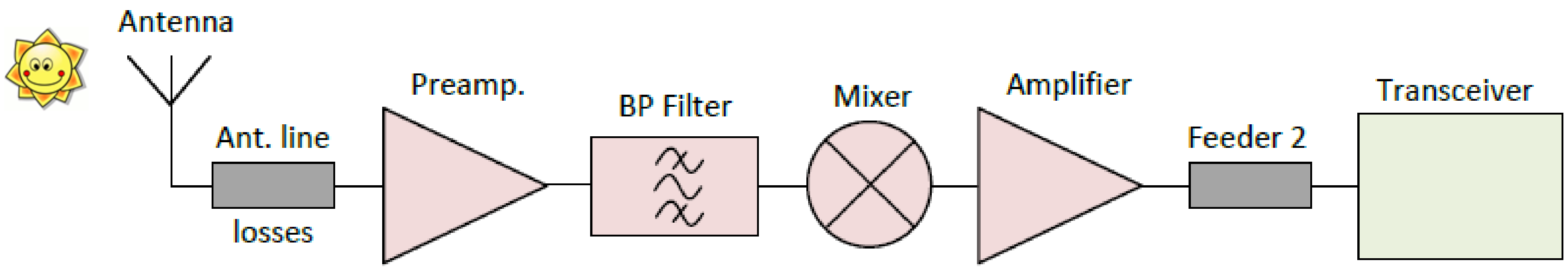


Step 2 : background noise BEFORE sun influence

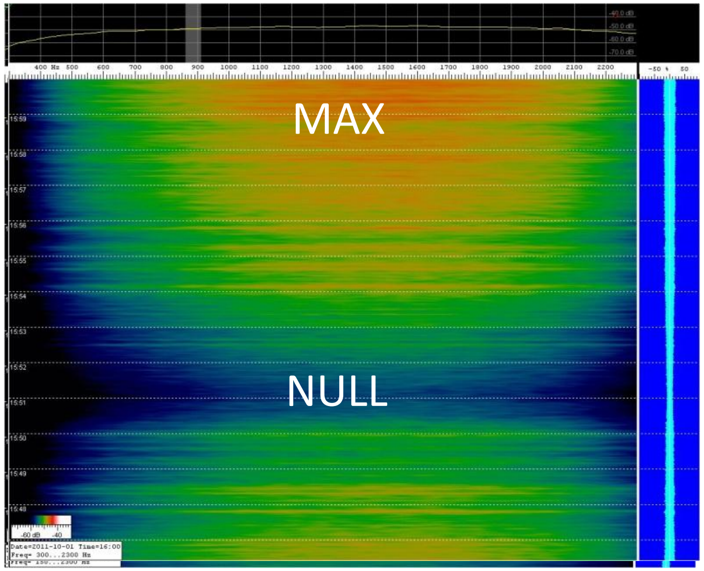


- Antenna is **connected** and receives (front, side & back antenna lobes) a **background** noise from sources as :
  - Earth.
  - Galactic.
  - Man-made.
- Correction needed to cope with **antenna line** losses (no ant. line losses in step 1).
- Measurement performed every 5° of azimuth, over the whole planned **azimuth range**.
- Spectrum Lab measures "N_{bgd} PRE", the noise power of the background **without** (before) **influence of the sun**.

Step 3 : Tracking the sun in Azimuth (*)

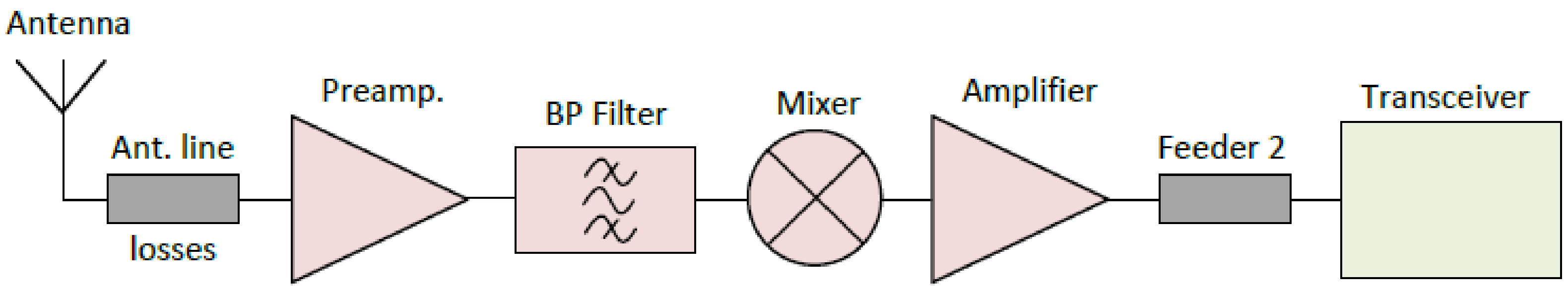


- Antenna is **connected** and receives (front, side & back antenna lobes) a **background** noise from sources as :
  - Earth.
  - Galactic.
  - Man-made.
  - Sun.
- Measurement (over the whole azimuth range) of the noise rise due to **presence of the sun**, on top of the background noise.



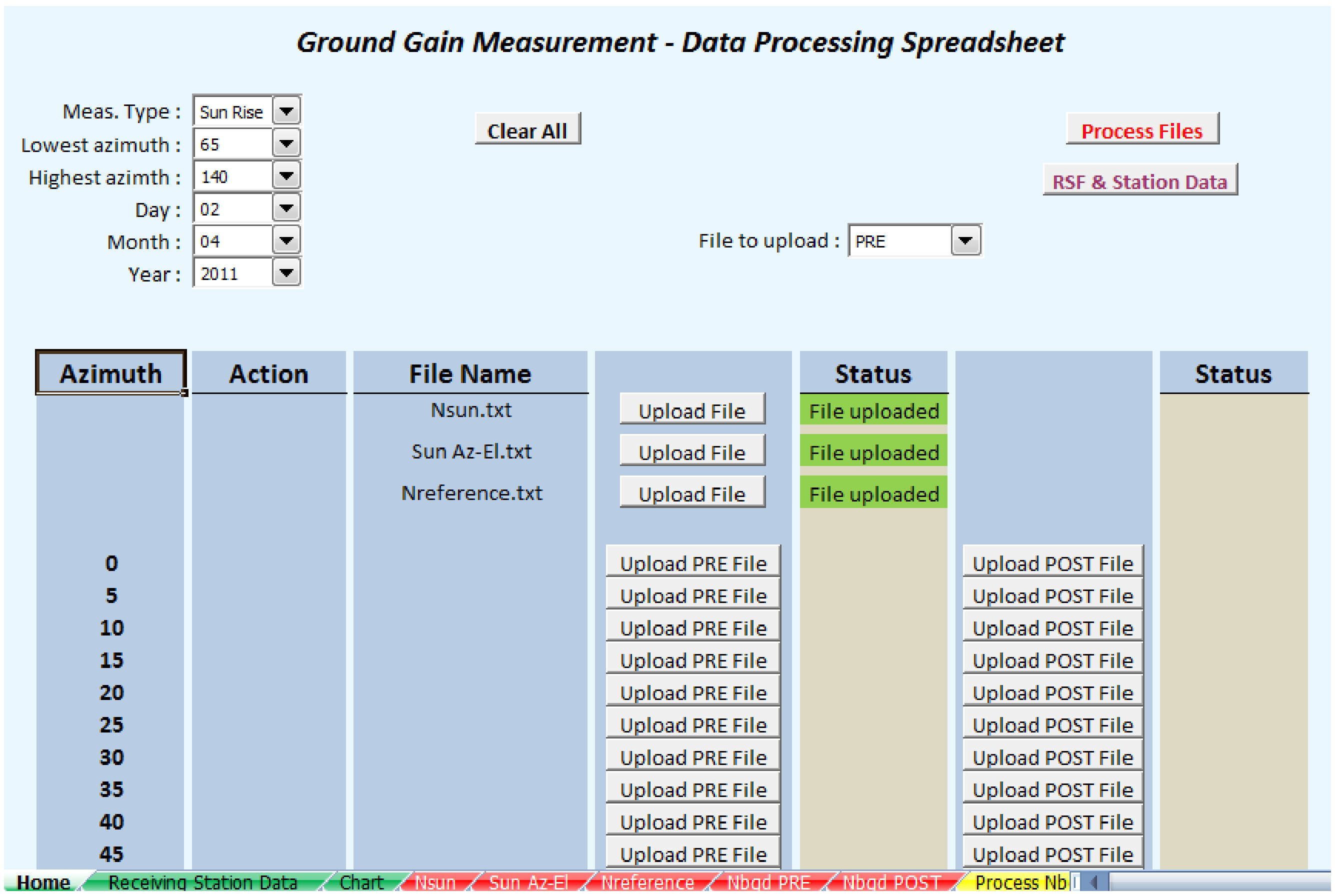
(*) : Better watch this slide in animated mode.

Step 4 : background noise AFTER sun influence



- Antenna is **connected** and receives (front, side & back antenna lobes) a **background** noise from sources as :
  - Earth.
  - Galactic.
  - Man-made.
- Measurement performed every 5° of azimuth, over the whole planned **azimuth range**.
- Spectrum Lab measures "N_{bgd} POST", the noise power of the background **without** (before) **influence of the sun**.

Post-processing (1/2)



- Use the “Ground Gain Sun Noise Measurement **Processing File**” (Excel 2007 ©) [7].
- Follow the procedure “Ground Gain Measurement **Procedure**” [8].
- Both to be downloaded at http://www.on4khg.be
- The output is a batch of **graphs in pdf format**.

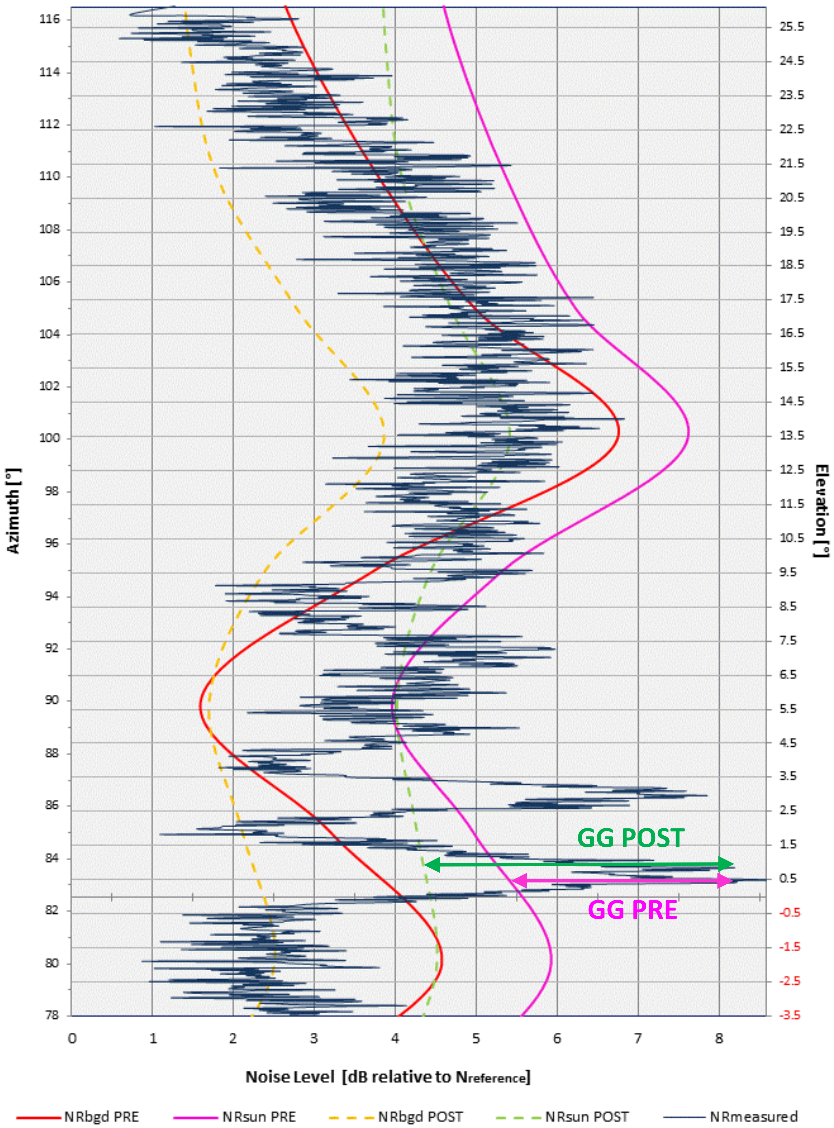
Post-processing (2/2)

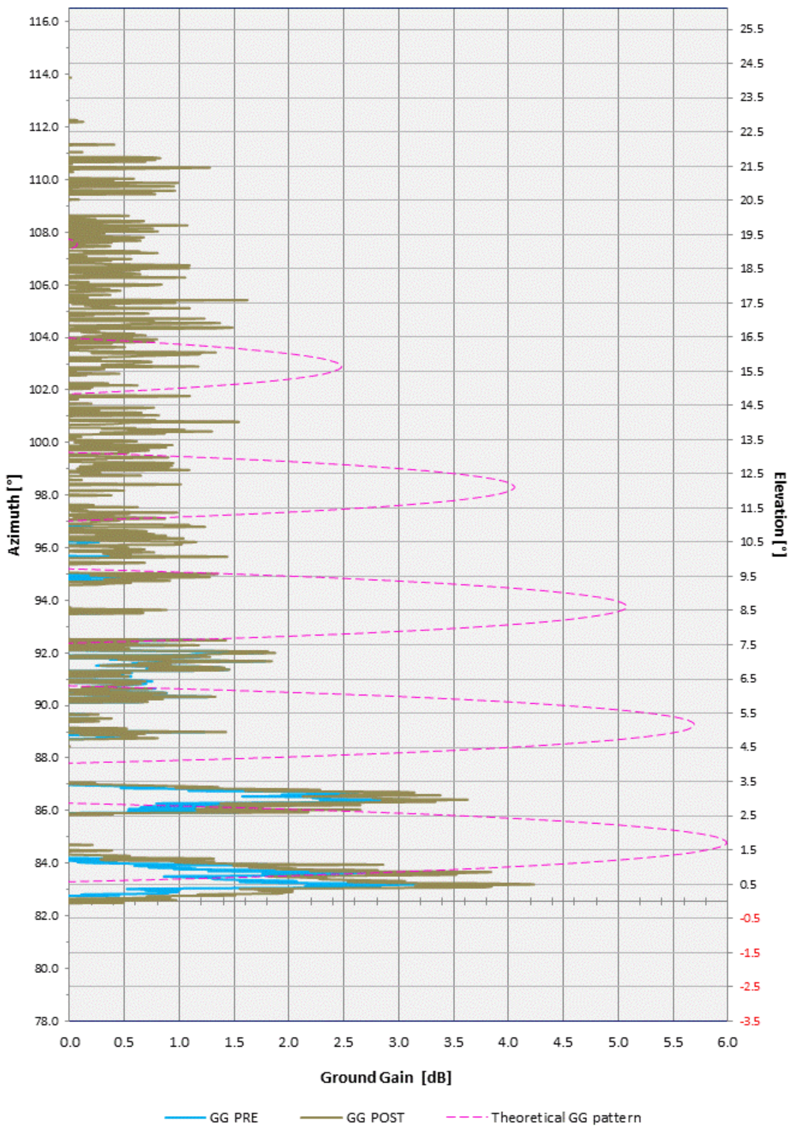
- The following slides show **examples** of output got out of the processing file (Measurement done at Sunrise & Sunset on April 2nd, 2011 @ station ON4KHG).

- The left graph shows the outcome of the measurement in dB relative to $N_{reference}$:
  - NR_{bgd} PRE (red) : the averaged noise rise (in dB) when replacing the 50Ω load by the antenna line **before** the sun noise tracking measurement. The variation with azimuth seen is due to the background noise, considering the sky noise doesn't vary much over the considered azimuth and measurement time span.
  - NR_{sun} PRE (purple) : this is the calculated value (in dB) of the noise increase that should be generated by the sun, on top of the background noise **NR_{bgd} PRE**, without ground influence.
  - NR_{bgd} POST (orange dashed) : like NR_{bgd} PRE but **after** the sun noise tracking measurement.
  - NR_{sun} POST (green dashed) : like NR_{sun} PRE but on top of the background noise **NR_{bgd} POST**.
  - $NR_{measured}$ (blue) : the measured noise rise (in dB) during the sun noise tracking measurement, i.e. including both the background noise and the sun noise with ground enhancement.

- The right graph indicates the absolute magnitude of the Ground Gain in dB :
  - GG PRE (light blue) : the magnitude of the Ground Gain (in dB) based on the background noise (NR_{bgd} PRE) **before** the sun noise tracking measurement.
  - GG POST (brown) : like GG PRE but **after** the sun noise tracking measurement.
  - Theoretical Ground Gain pattern over a perfectly reflective flat ground (purple dashed) : self-explanatory, taking into account the radiation pattern of the antenna (here the 12-element DK7ZB at 17.3m agl).

Result of the post-processing – Example Sunrise

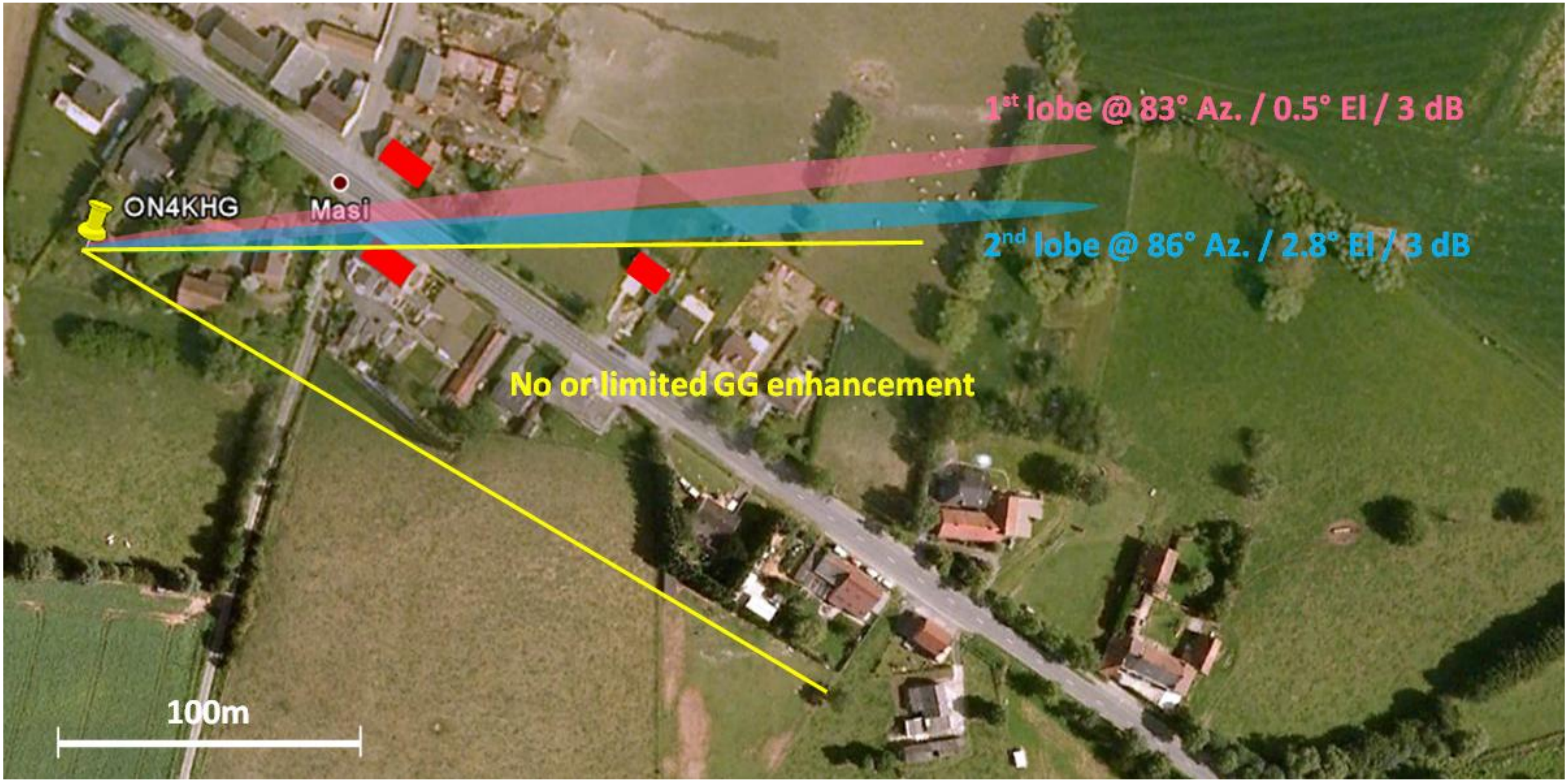




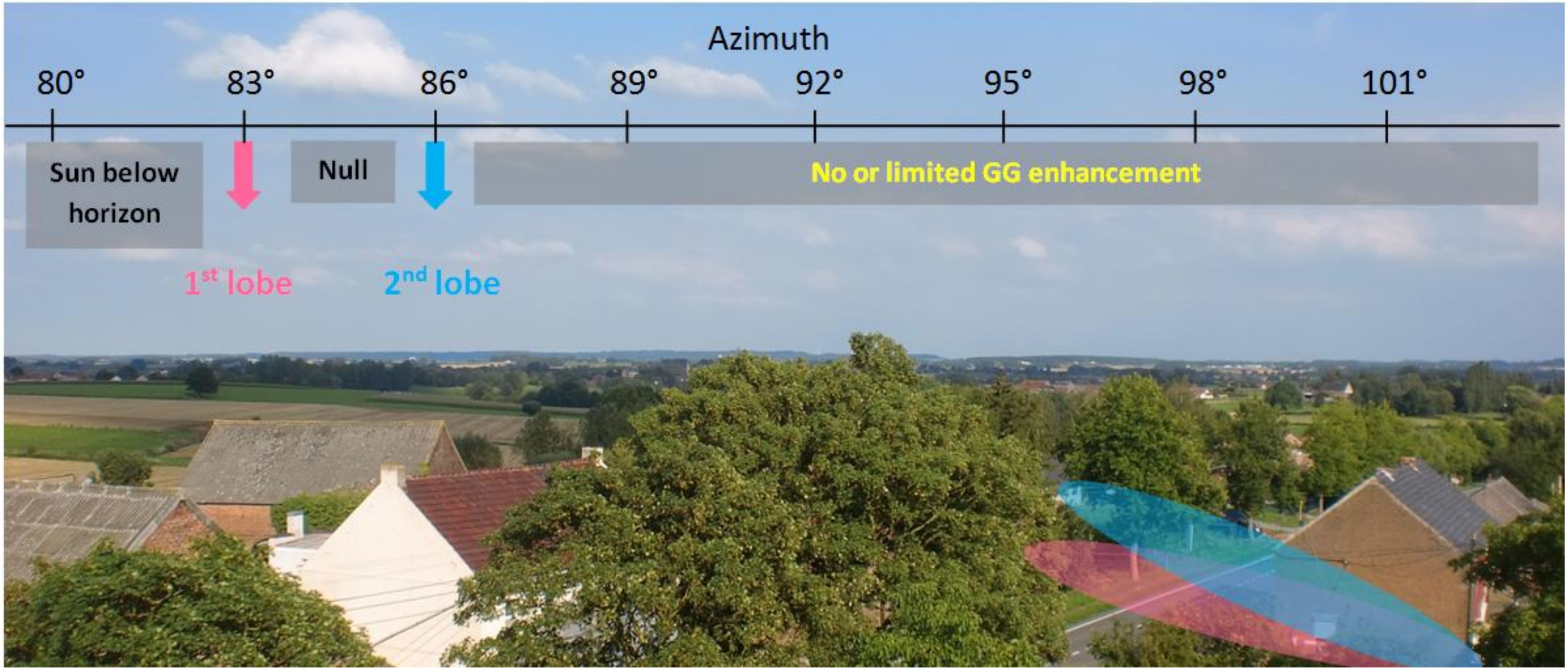
Analysis of the results – Sunrise

- Date of measurement : April 2nd, 2011.
- Azimuth range : 79° > 115°.
- Sun elevation range (the antenna stays always on 0° elevation) : -3° > 25°.
- Two **significant lobes** at 0.5° and 2.8° elevation ; at higher elevations, the measurement is either **too noisy** or there is no or very **limited** Ground Gain enhancement.
- **3 dB in average** of Ground Gain enhancement for the two lobes.
- The elevation angles are **lower** than the theoretical ones (purple dashed). This is due to the sloping ground in front of the antenna in these azimuths.
- Not surprisingly, the two lobes build **between** houses (see next slide), but where the terrain is cluttered with houses in the area where the lobe should be building, there is **no noticeable** (or very limited) Ground Gain enhancement.

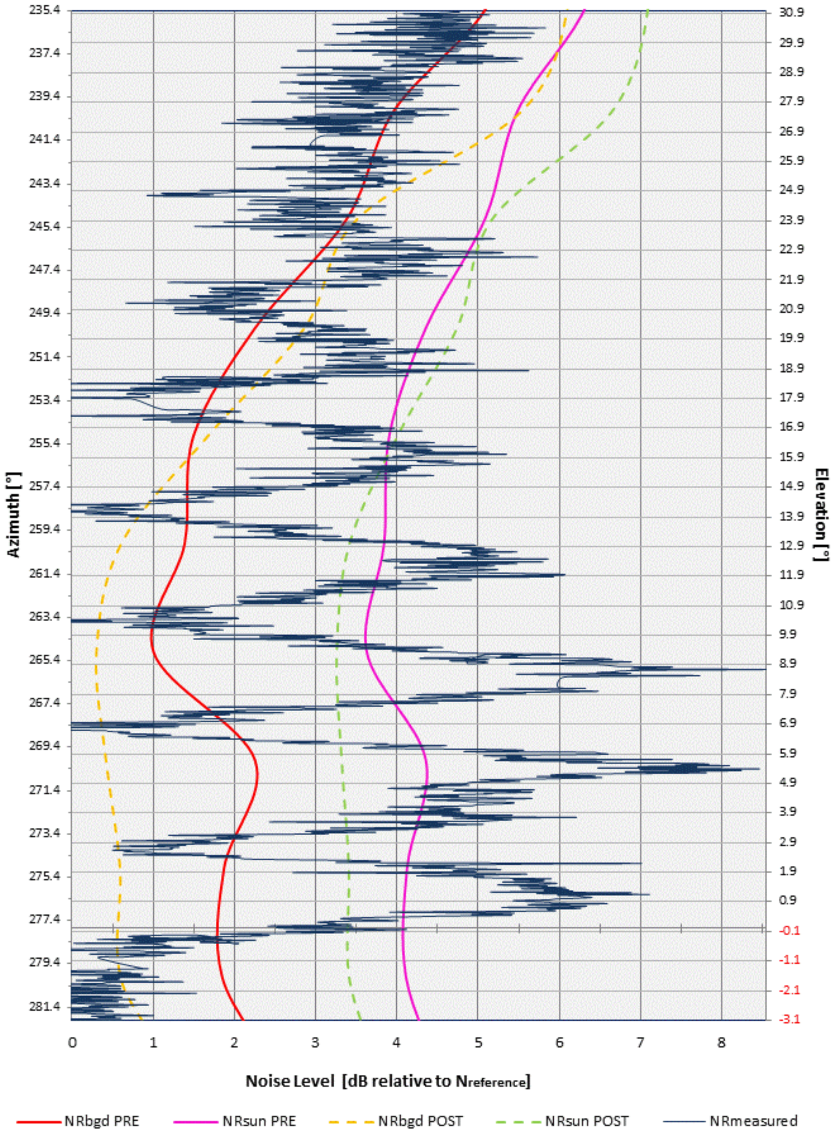
Terrain clutter - Sunrise

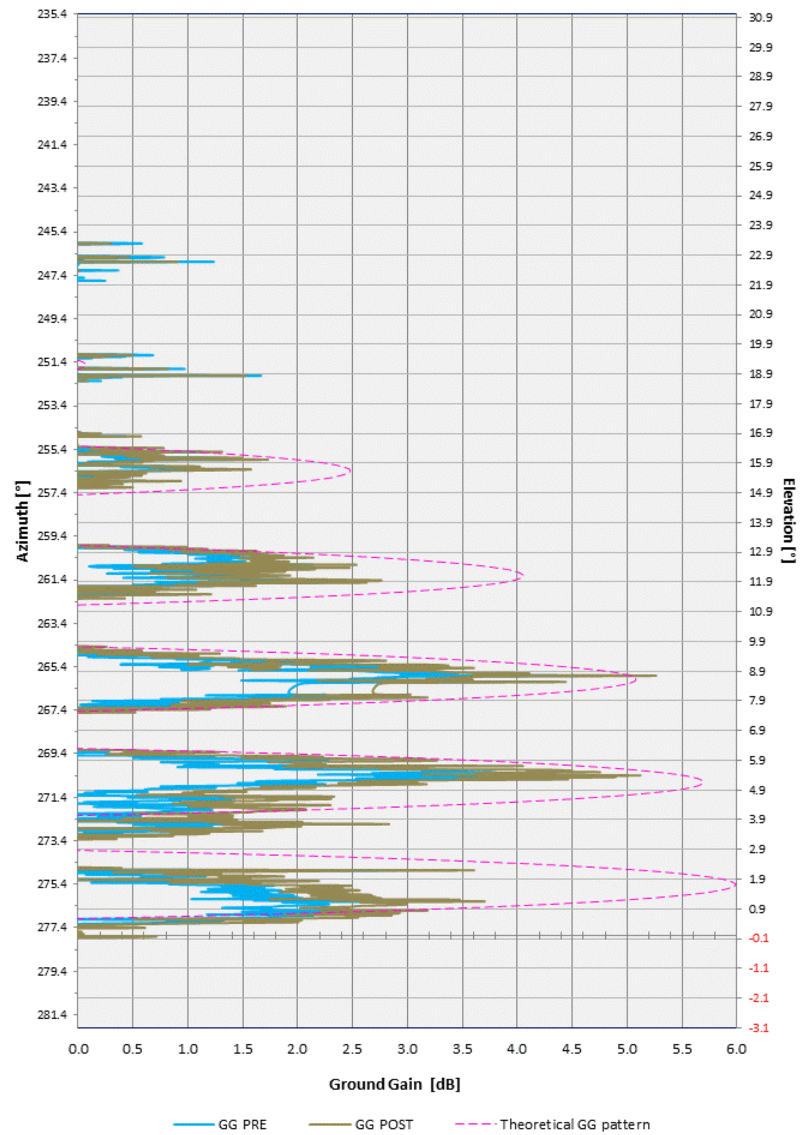


Panoramic view - Sunrise



Result of the post-processing – Example Sunset

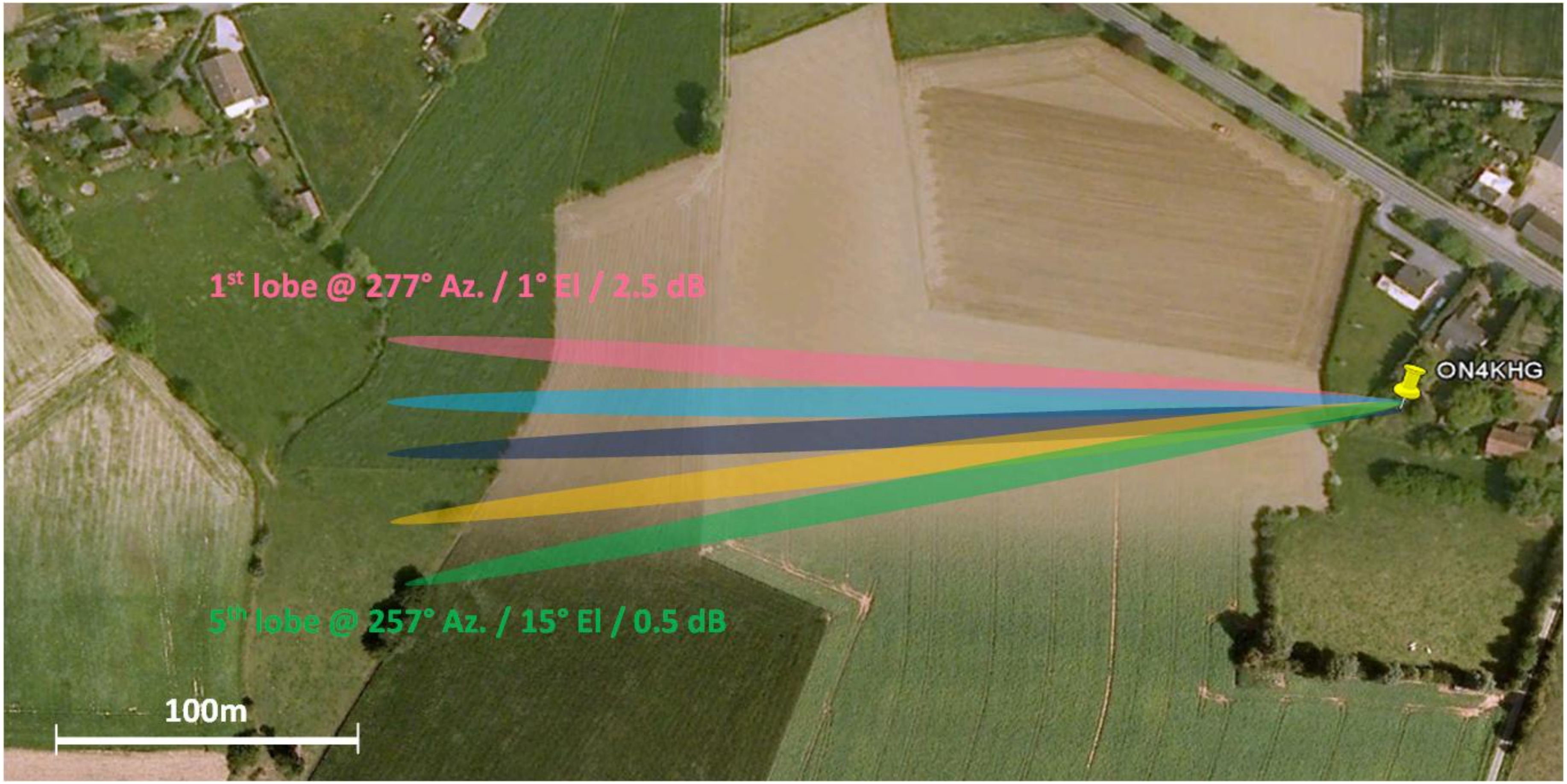




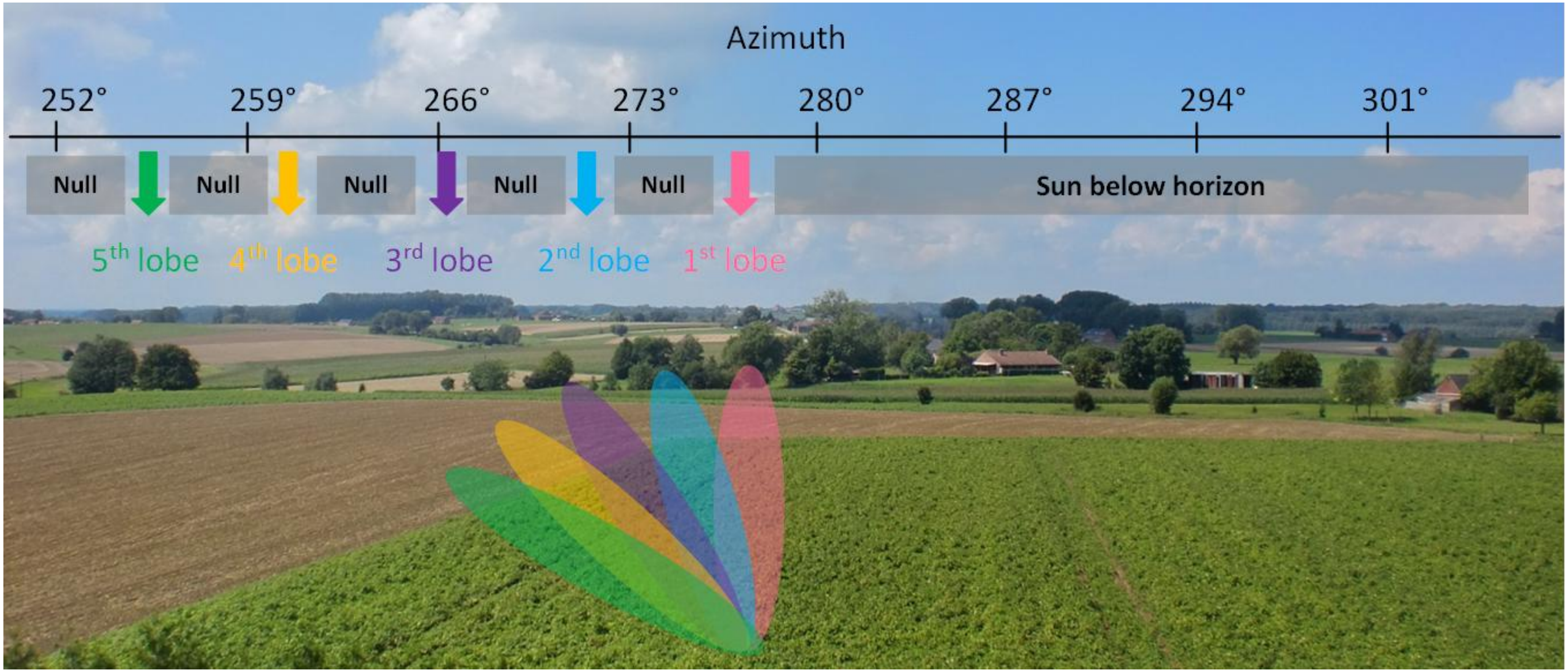
Analysis of the results - Sunset

- Date of measurement : April 2nd, 2011.
- Azimuth range : 243° > 281°.
- Sun elevation range (the antenna stays always on 0° elevation) : 25° > -3°.
- **Five distinctive** Ground Gain lobes at 1°, 5°, 8°, 11.5° and 15.4° elevation.
- **Up to 4.5 dB** enhancement for the second and third lobes ; 2.5 dB for the first and fourth lobes.
- The first lobe exhibits **less** Ground Gain enhancement than one would have expected. With the antenna at 17.3m agl, this lobe builds between 99m and 3400m from the antenna (theoretical figures over flat ground) but in this direction there are **big farms** at 800m, 1.1km and 1.2km. Although these are too distant to be visible on the next slides, they do seem to **affect** the formation of the first lobe. However, at the closer ranges, where the second and third lobes are building, there are only open fields and Ground Gain enhancement is in fact observed.
- The elevation angles are a bit **lower** than the theoretical ones, again because of the slightly sloping ground (less tilted than in the sunrise direction).

Terrain clutter - Sunset



Panoramic view - Sunset



Accuracy

- The measurement **method** described here will easily highlight the elevation **radiation pattern geometry**. Regarding the **magnitude** of the lobes, this isn't that easy.
- At 144 MHz and for the station considered here, the calculated **noise rise** due to the **sun** amounts to 2.5 dB at best when the background noise level is low, and to 0.5 dB when the background noise is high (very limited "hot"-"cold" sources span).
- The **background** noise is usually varying during the whole measurement time span.
- Preamplifier (in front of the Transceiver or inside the Transverter) gain can **vary in time** and when **changing** between the 50Ω load and a slightly mismatched antenna.
- The accuracy of the extrapolated Radio Solar Flux (**RSF**) is also very **questionable**.
- This presentation focuses on **144 MHz**. What about other frequencies ?
  - **50 MHz** : if conditions of flatness and un-cluttered nearby area are met, benefit can definitely be taken of the Ground Gain. However, it is almost impossible to measure it, due to the RSF lower than on 144 MHz and higher background (galactic) noise.
  - **432 MHz** : depends on same conditions as on 50 and 144 MHz, as well as ground depth penetration at this frequency (dielectric properties of the ground). Apparently VK7MO & DL7APV [9] have shown evidence of Ground Gain at 432 MHz.
- The **span** of azimuth ranges over which the Ground Gain can be measured is determined by the **latitude**. Northern locations will experience broader spans whereas southern ones will experience narrower.

Case Studies – Correlation with EME traffic

- Ground Gain **geometry** can also be assessed through **EME traffic**.
- Antenna system **without elevation** (antenna elevation = 0°).
- Moon elevation ranging from 0° to 25°.
- **Representative** amount of data collected.
- Data / graphs processed in Excel ©.
- Moon azimuth/elevation written down for every QSO or calculated *a posteriori.*
- **Analysis** of the traffic confirms theoretical assumptions.
- The following slides expose the case of **4 stations** relying on Ground Gain for their EME traffic :
  - ON4KHG.
  - ON7EH.
  - W5UWB.
  - DL4DWA.
- **Thanks** all for your respective contributions.

Case Studies – Overview (1/3)

	ON4KHG	ON7EH	DL4DWA	W5UWB
Name	Gaëtan	Michel	Uwe	John
QRA Locator	JO10XO	JO20FV	JO61QH	EL17AX
Environment	Rural	Residential / Semi-urban (suburb)	Semi-urban	Rural
Terrain	Slightly hilly	Flat	Flat	Flat
Power out [W]	300	250	500	1500
Antenna	12-el DK7ZB	12-el M²	13-el F9FT	1991-2005 : 17-el M² > 2005 : 21-el M²
Antenna length [λ]	3.83	2.84	2.12	1991-2005 : 4.83 > 2005 : 8.05
Antenna Gain [dBd]	14.2	12.7	12.0	1991-2005 : 14.7 > 2005 : 17.0
Antenna height [m agl]	17.3	9.5	23.0	18.0
ERP [kW]	6.2	4.2	6.6	1991-2005 : 33.6 > 2005 : 57.0

Case Studies – Overview (2/3)

	ON4KHG	ON7EH	DL4DWA	W5UWB
Distance from antenna where maximum of 1st lobe builds [m]	583	175	1014	606
Furthest distance from antenna up to which 1st lobe builds [m]	3399	1021	5911	3533
Amount of EME QSO's considered in the analysis	397	526	Sampling of 30	1100
# Initials worked	271	300	306	570
# DXCC's worked	98	105	91	-

Rem : The 1st elevation lobe is the one building the furthest from the antenna. In the coming slides titled "Case Studies – Call-sign – Ground Clutter", the circle in red dashed indicates the distance from the antenna where the **maximum** of the 1st lobe builds (assuming the ground is flat).

Case Studies – Overview (3/3)

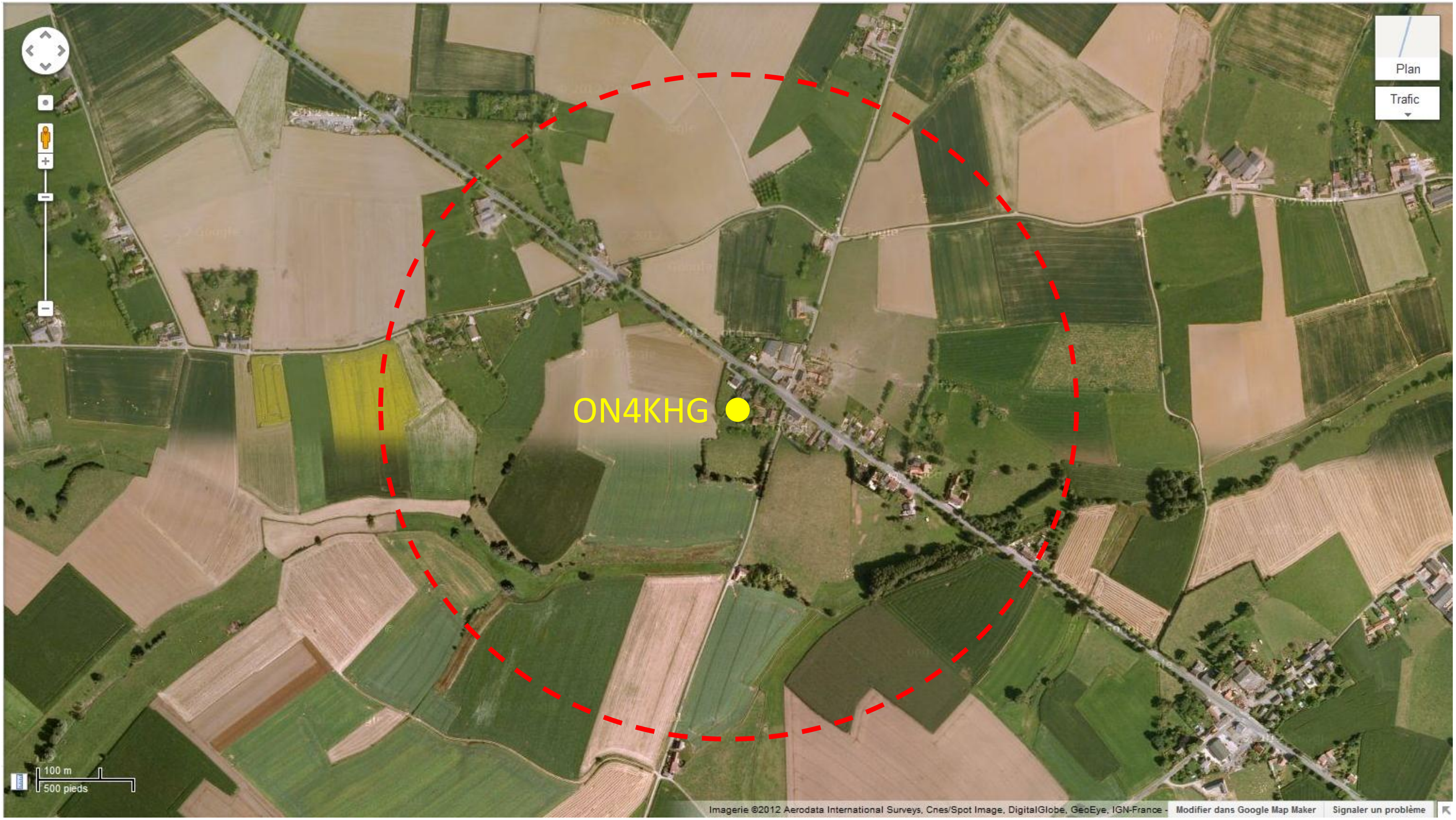
Theoretical Simulations (flat ground)	ON4KHG	ON7EH	DL4DWA	W5UWB
Elevation 1st lobe [°]	**1.7**	**3.1**	**1.3**	**1.6**
Ground Gain 1st lobe Perf/Gd/Pr [dB]	6.0/5.9/5.9	5.9/5.8/5.7	6.0/6.0/5.9	5.8/5.8/5.7
Elevation 2nd lobe [°]	**5.2**	**9.4**	**3.9**	**4.9**
Ground Gain 2nd lobe Perf/Gd/Pr [dB]	5.7/5.5/5.3	5.2/4.9/4.5	5.9/5.8/5.6	4.4/4.2/4.0
Elevation 3rd lobe [°]	**8.6**	**15.8**	**6.5**	**8.1**
Ground Gain 3rd lobe Perf/Gd/Pr [dB]	5.1/4.8/4.4	3.5/3.0/2.3	5.7/5.5/5.2	1.1/0.8/0.4
Elevation 4th lobe [°]	**12.1**	**22.2**	**9.1**	**11.3**
Ground Gain 4th lobe Perf/Gd/Pr [dB]	4.1/3.6/3.1	0.1/-0.6/-1.5	5.4/5.1/4.7	-5.7/-6.1/-6.6
Elevation 5th lobe [°]	**15.6**	**-**	**11.7**	**13.9**
Ground Gain 5th lobe Perf/Gd/Pr [dB]	2.5/2.0/1.3	-	5.0/4.6/4.1	-27/-28/-28
Elevation 6th lobe [°]	**19.2**	**-**	**14.4**	**15.8**
Ground Gain 6th lobe Perf/Gd/Pr [dB]	0.1/-0.6/-1.3	-	4.5/4.0/3.4	-16/-17/-18
Elevation 7th lobe [°]	**22.8**	**-**	**17.1**	**18.7**
Ground Gain 7th lobe Perf/Gd/Pr [dB]	-3.7/-4.4/-5.3	-	3.7/3.2/2.5	-7.0/-7.0/-8.0
Elevation 8th lobe [°]	**-**	**-**	**19.8**	**22.1**
Ground Gain 8th lobe Perf/Gd/Pr [dB]	-	-	2.7/2.1/1.3	-5.0/-6.0/-7.0

Perf = Perfect Ground / Gd = Good Ground / Pr = Poor Ground.

Case Studies – ON4KHG – Ground Clutter

- - - Distance where max. of 1st lobe builds

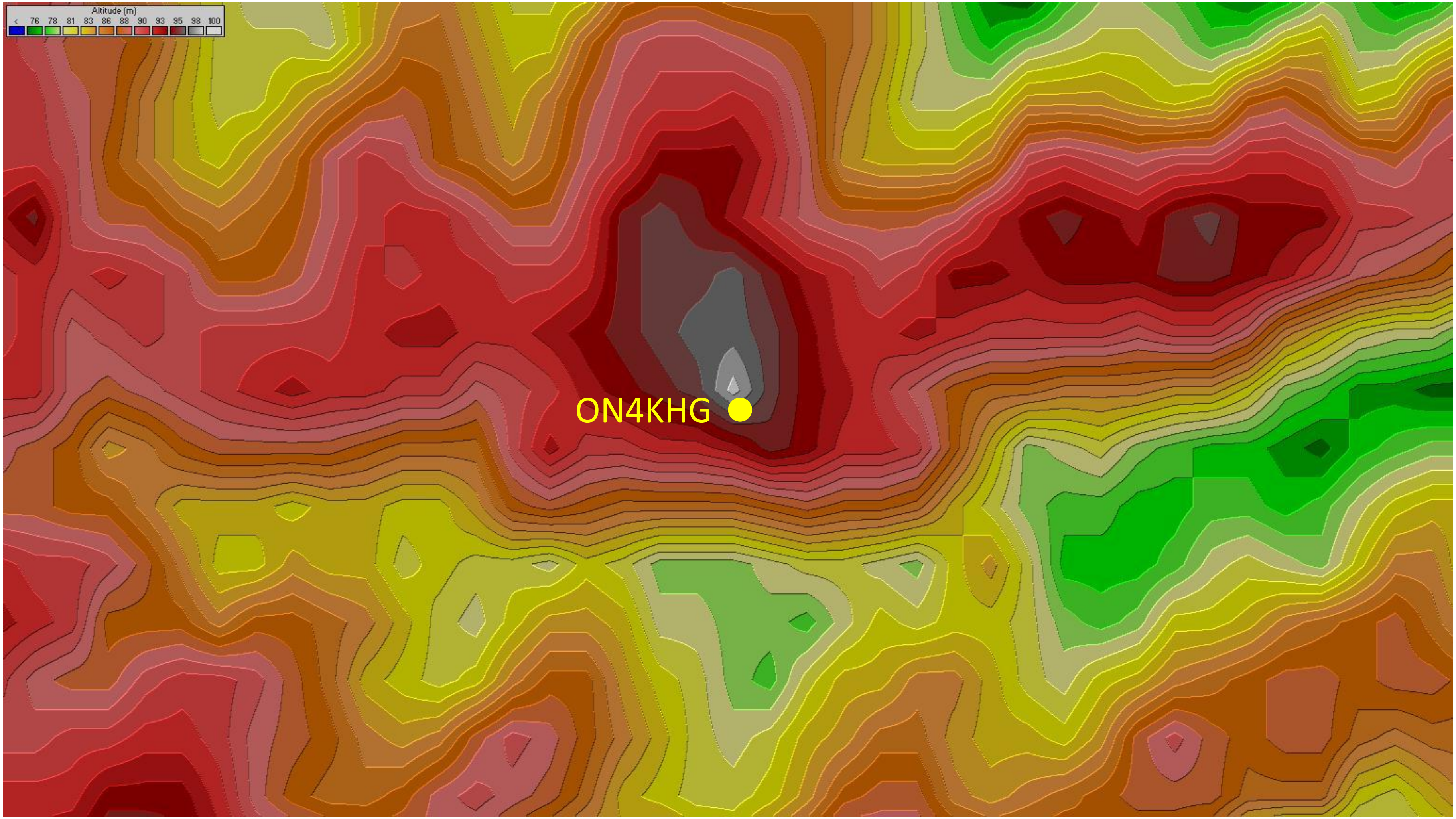
Picture width*height [km] : 2.3*1.3



Case Studies – ON4KHG – Antenna

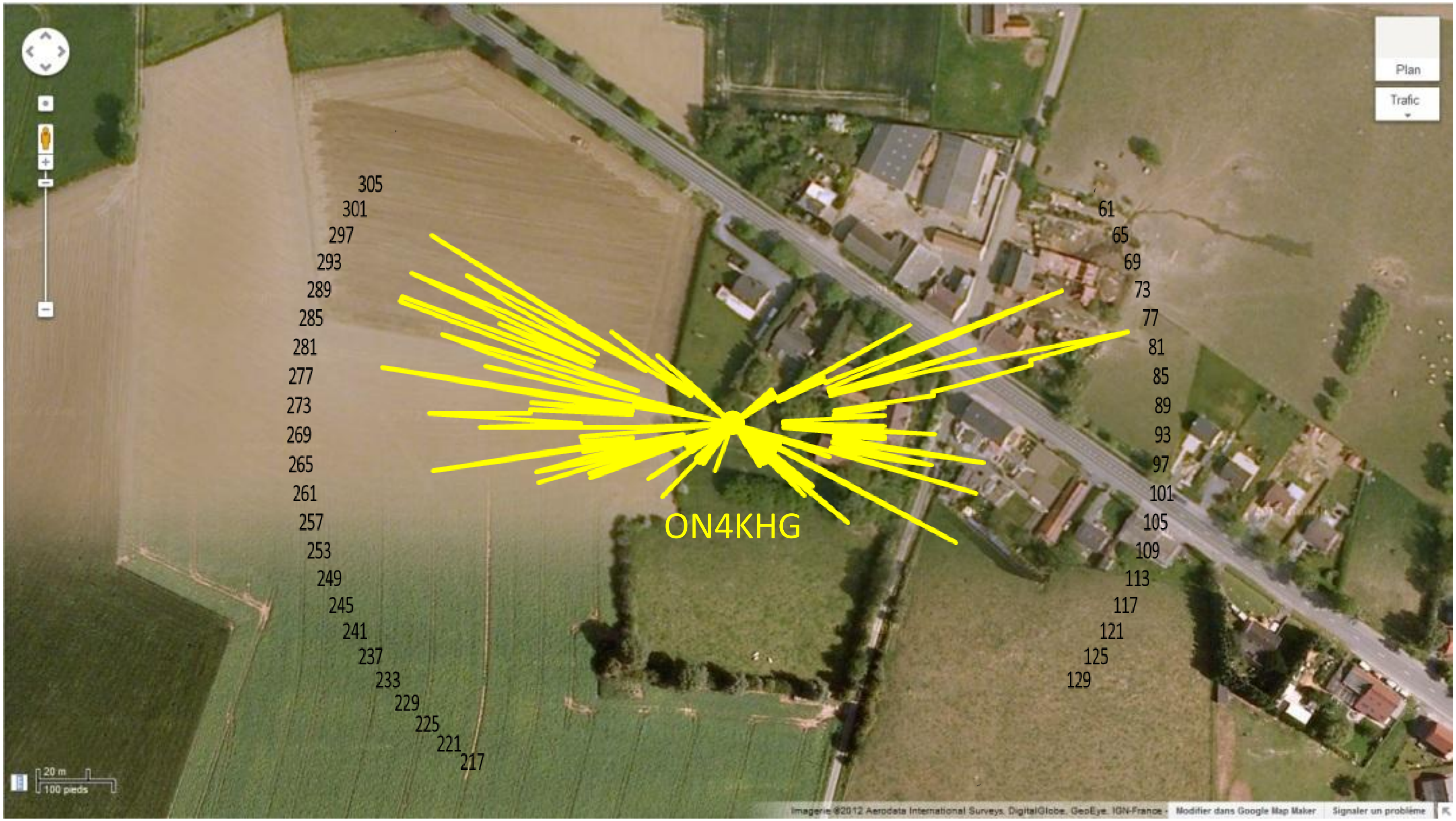
Case Studies – ON4KHG – Relief

Altitude span [m] : 76 ➔ 100
Picture width*height [km] : 2.3*1.3

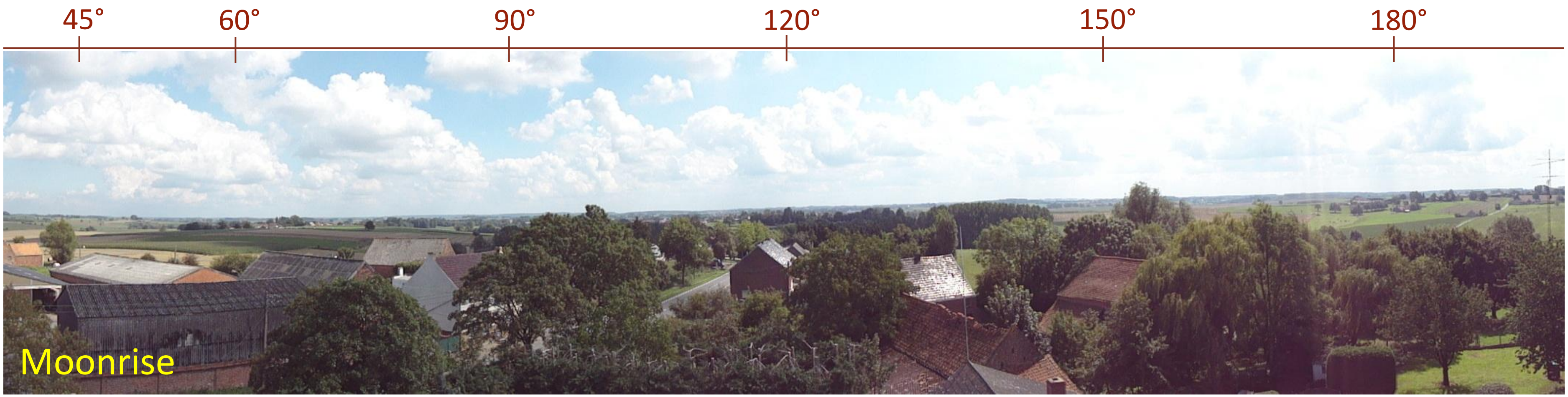


Case Studies – ON4KHG – Relative # QSO's vs Azimuth

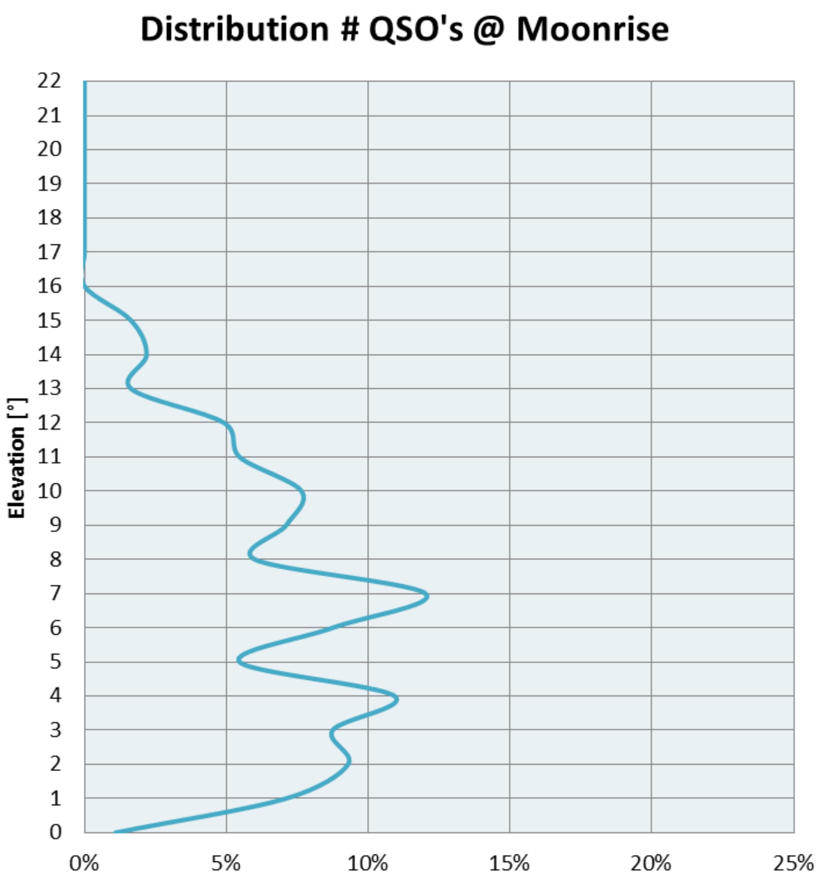
Picture width*height [m] : 570*320

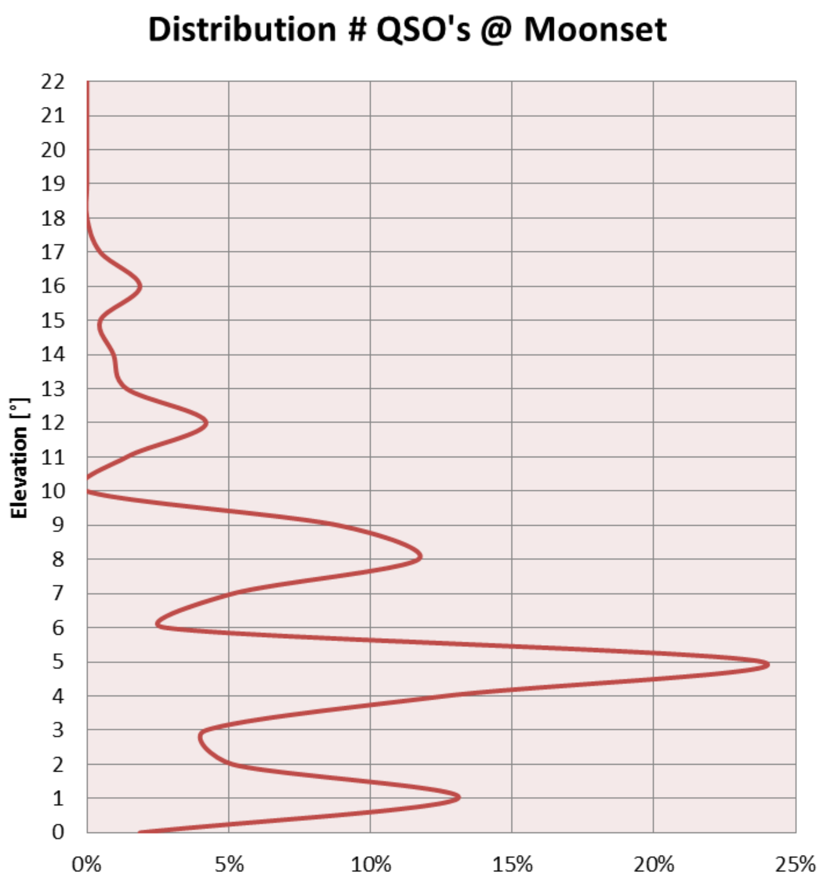


Case Studies – ON4KHG – Panoramic views



Case Studies – ON4KHG – Distribution of EME QSO's vs elevation





No real Ground Gain enhancement at Moonrise.

Marked Ground Gain lobes, except the 1st one.

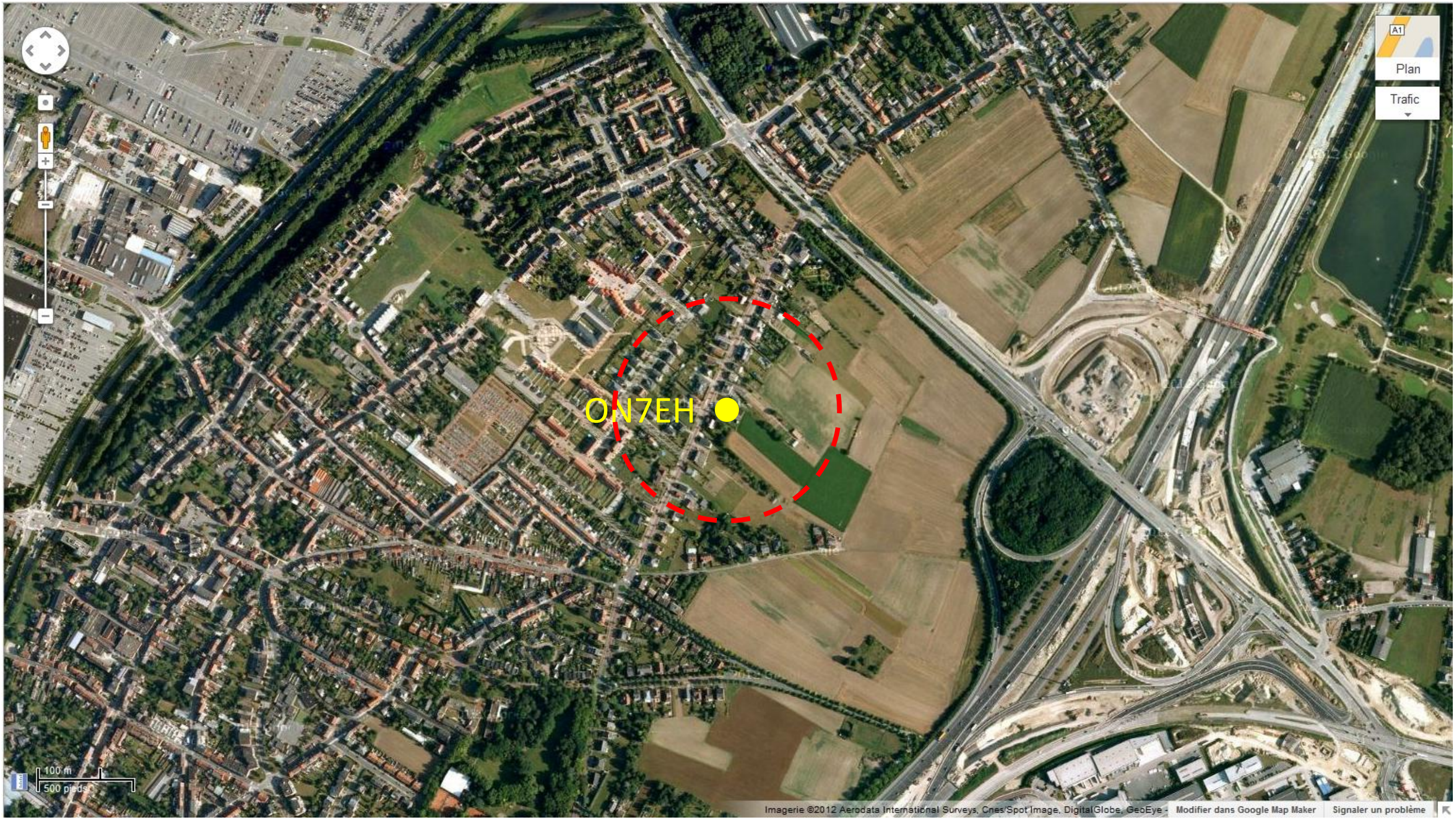
Case Studies – ON4KHG - Summary

- The Moonrise graph shows fuzzy max. & nulls = **limited** Ground Gain.
- Sun noise measurements (as explained before) have demonstrated :
  - 2-3 dB maximum of Ground Gain at Moonrise (over a limited azimuth range).
  - Around 4.5 dB of Ground Gain at Moonset.
- Writing down the JT65 RX level over almost 400 QSO's indicates a difference of 1.5 dB **in favour** of Moonset, **confirming** the statement above.
- Due to the antenna height, the 1st lobe at Moonset builds over a **wide area** (not fully flat and cluttered with vegetation and buildings) ➔ its magnitude is not matching with the theory (flat perfect ground).
- The vegetation and buildings (though not very dense) present over most of the Moonrise azimuth range **prevent** the Ground Gain to **build efficiently**.
- Though the (free space elevation) radiation pattern of the 12-el DK7ZB is somehow narrow, the 5th lobe (16° elevation for the antenna 17.3m agl) is **still useful** at Moonset.
- 55% of the amount of QSO's are done at Moonset and 45% at Moonrise.

Case Studies – ON7EH – Ground Clutter

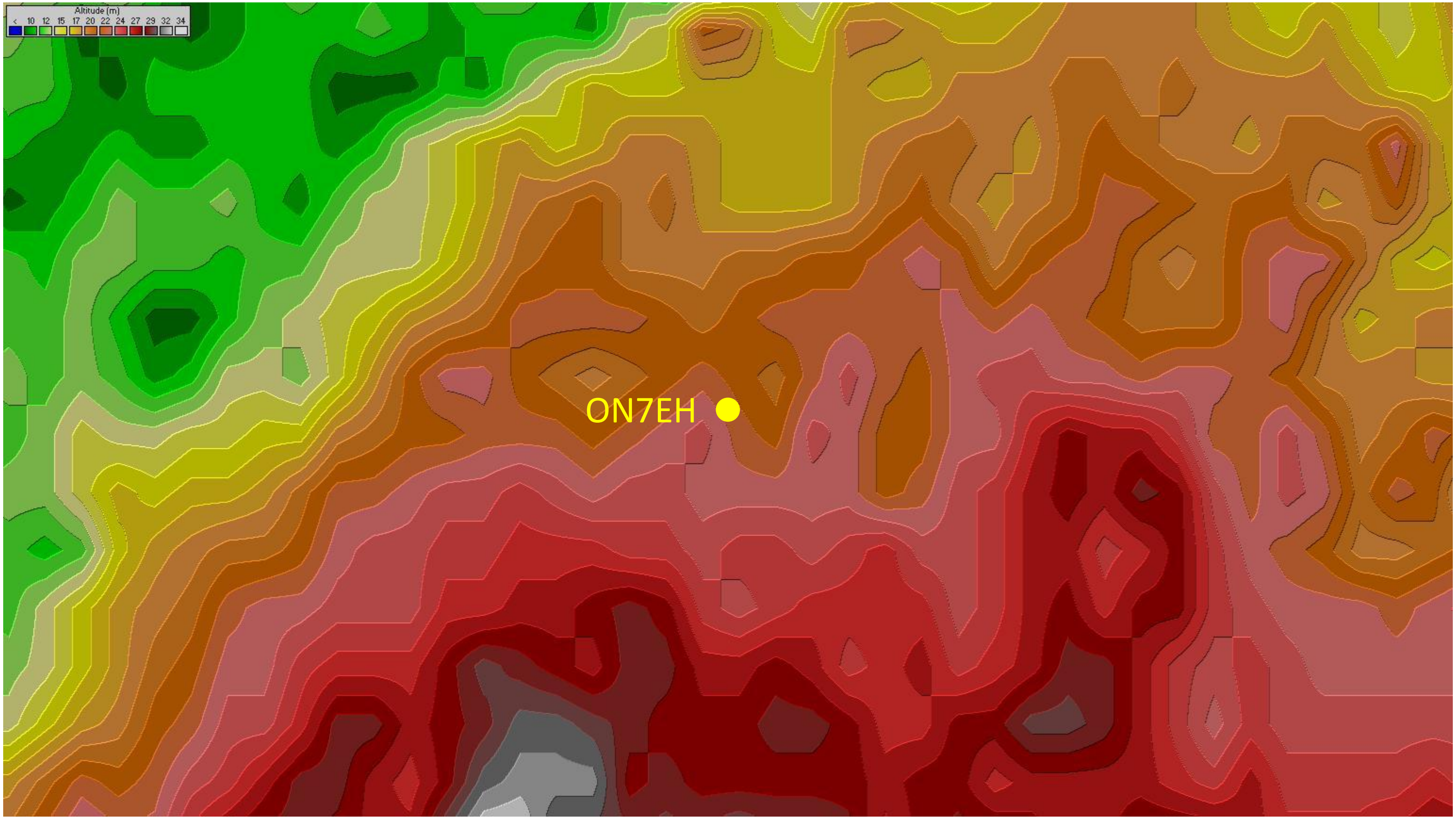
- - - Distance where max. of 1st lobe builds

Picture width*height [km] : 2.3*1.3



Case Studies – ON7EH – Relief

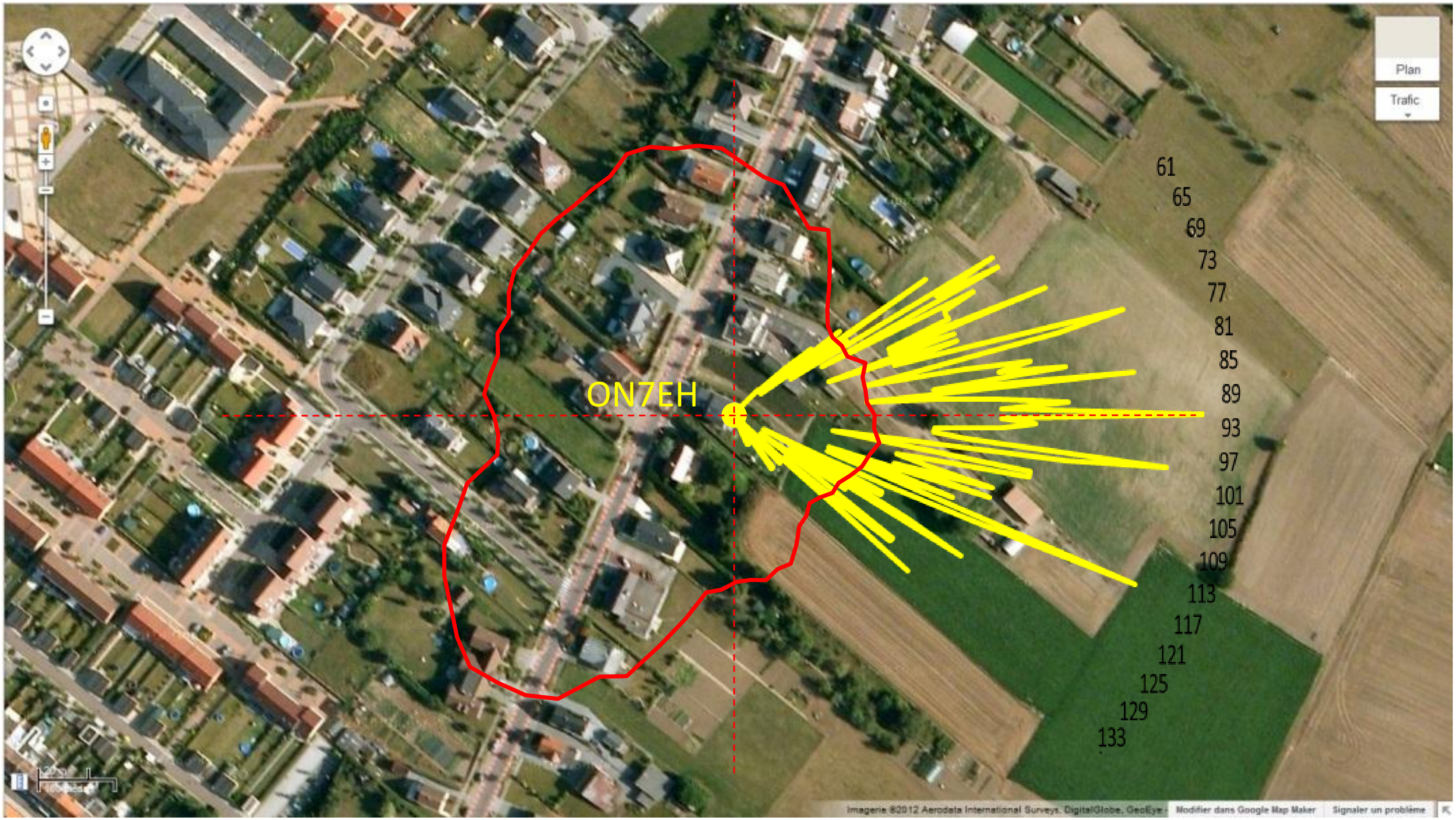
Altitude span [m] : 10 ➔ 34
Picture width*height [km] : 2.3*1.3



Case Studies – ON7EH – Relative # QSO's vs Azimuth

Relative noise level

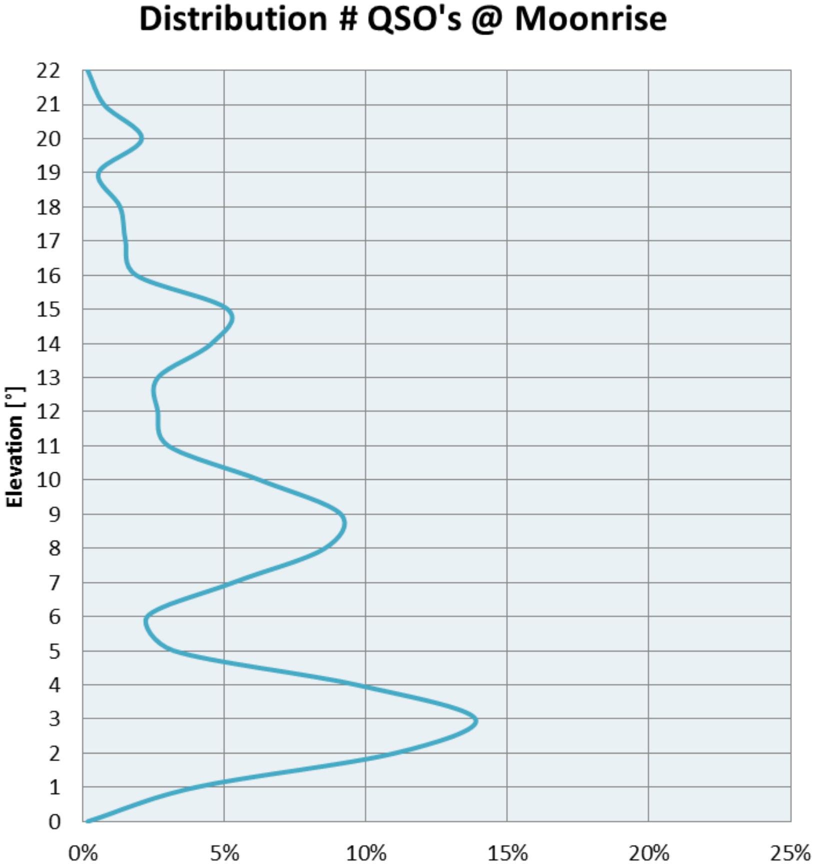
Picture width*height [m] : 570*320



Case Studies – ON7EH – Panoramic view & Antenna

50° 75° 100° 125° 150°

Case Studies – ON7EH – Distribution of EME QSO's vs Elevation & Summary



Almost **no QSO's at Moonset**, due to man-made noise & ground clutter.

- **High** man-made **noise** in the Brussels' suburb prevent Moonset operation.
- **Flat** and almost **un-cluttered** ground at Moonrise provide **excellent Ground Gain** magnitude.
- Effective elevation pattern **matching** with theoretical simulations [2] ➔ 3.1°, 9.4°, 15.8° & 22.2°.
- The relatively **broad** (free space) vertical plane (H-plane) radiation pattern of the antenna allows usage of the 4th lobe, at 20-22° elevation.
- At 9.5m agl, the Ground Gain lobes build over a **limited area**, reducing likelihood of too high altitude difference span (irregularities) and ground clutter occupancy.
- Not surprisingly, the **noise** (of any kind) seems Ground Gain **enhanced**, as it slightly increases over exactly the same azimuth range within which QSO's are made.
- Decrease of the magnitude of the elevation lobes in line with theory.

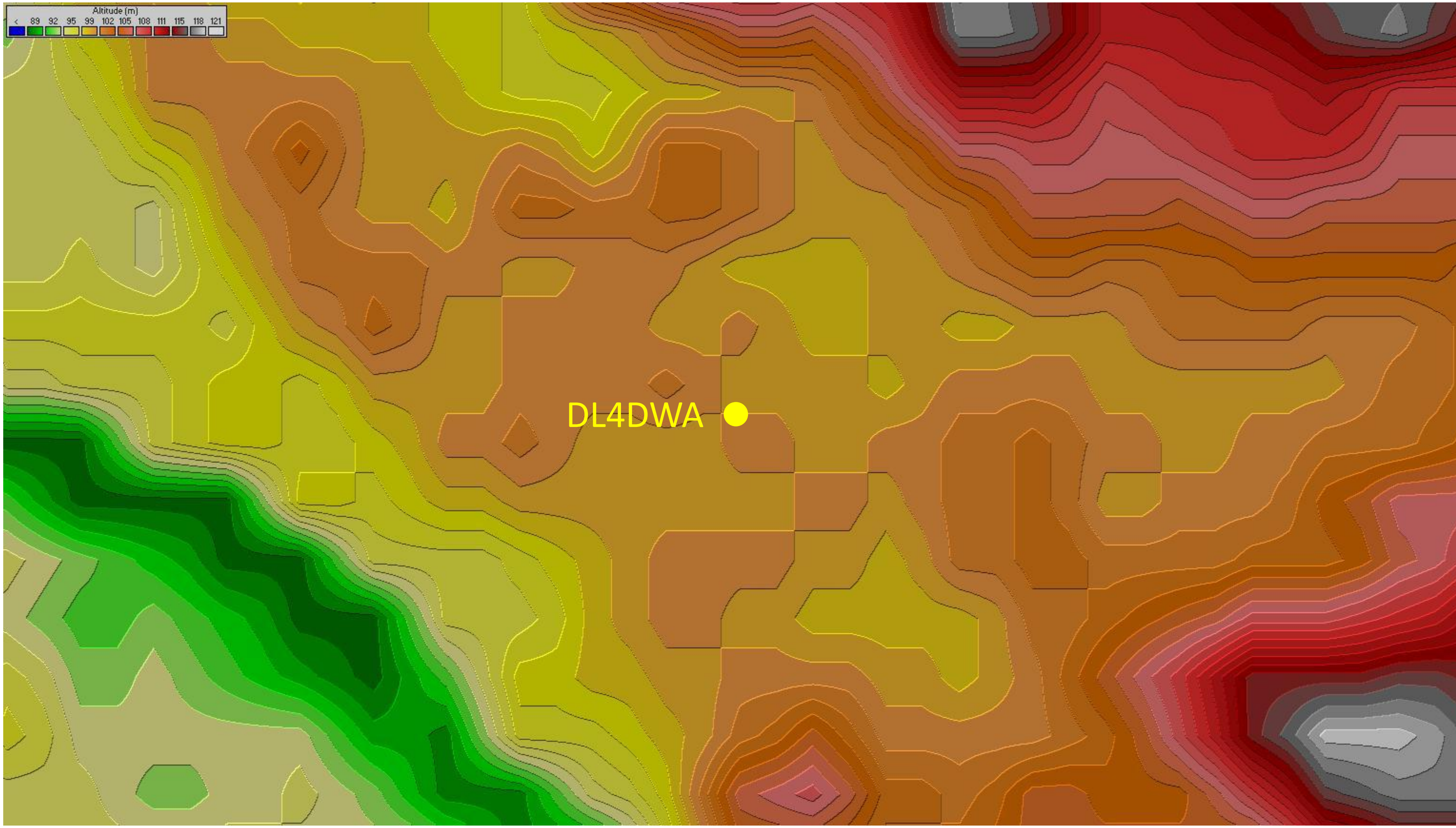
Case Studies – DL4DWA – Ground Clutter

- - - Distance where max. of 1st lobe builds

Picture width*height [km] : 2.3*1.3

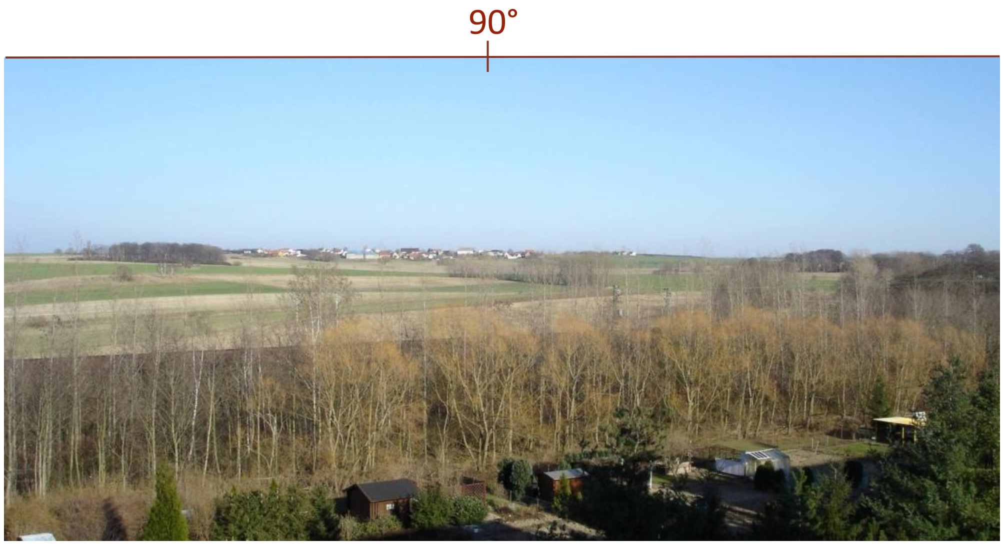
Case Studies – DL4DWA – Relief

Altitude span [m] : 89 ➔ 121
Picture width*height [km] : 2.3*1.3



Case Studies – DL4DWA – Antenna & Summary

- 20 years old antenna with **only** 12 dBd of free space gain (same as nowadays 8-el DK7ZB).
- Antenna **high** above the ground (23m) means Ground Gain lobe building over a **wide area** ➔ overall **limited** Ground Gain (due to clutter and ground irregularities), though very **flat** in the close vicinity of the antenna.

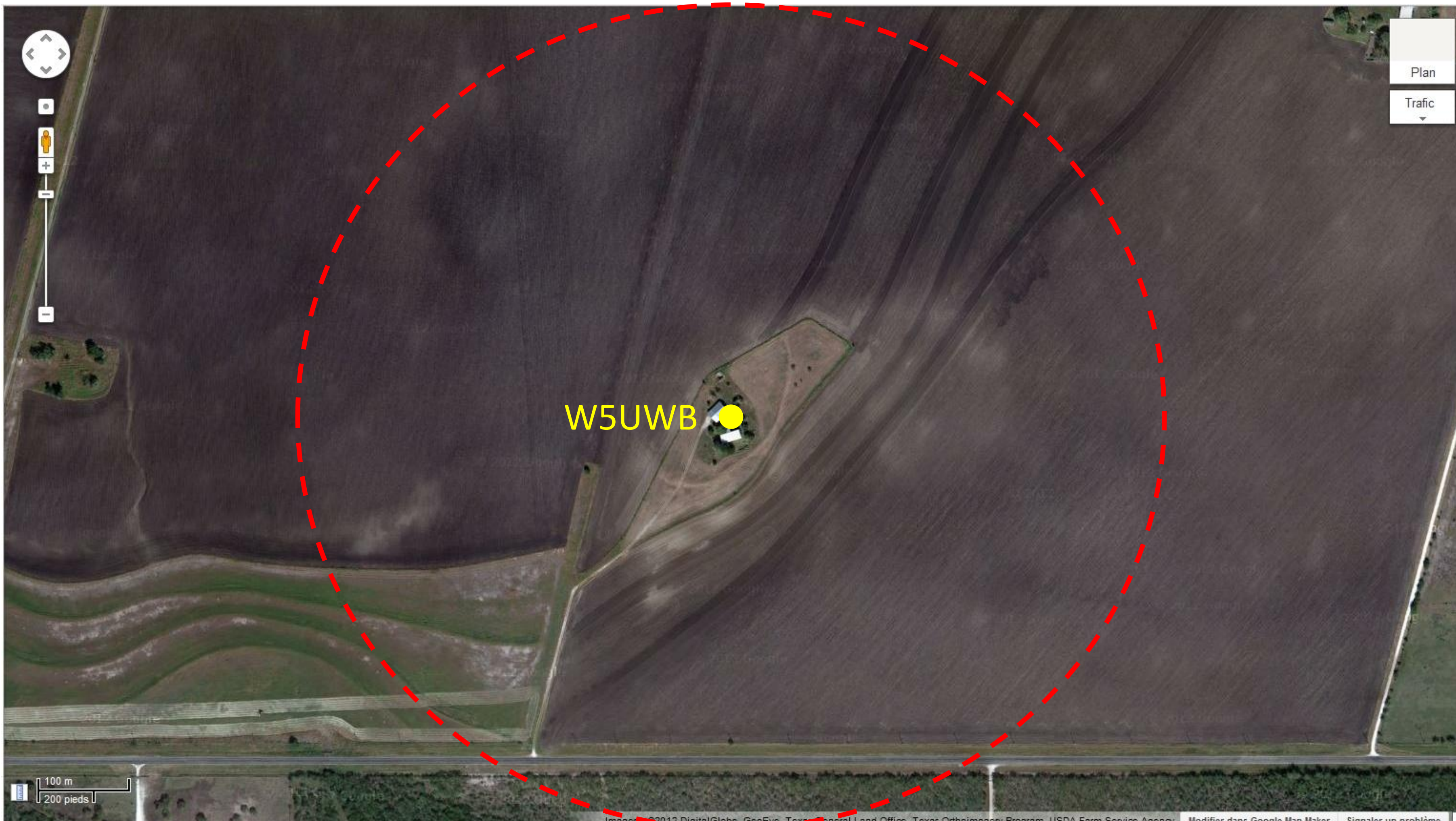


- **Most** of the QSO's at Moonset are made on the 1st elevation lobe. Indeed, in this case, the antenna **height helps** in overlooking the ground occupancy (the village) in this direction, given this lobe builds over an un-cluttered area.
- However, at Moonset, building of "higher" elevation lobes **suffers** from substantial **attenuation** introduced by the ground occupancy (given these build closer to the antenna, over the village).

Case Studies – W5UWB – Ground Clutter

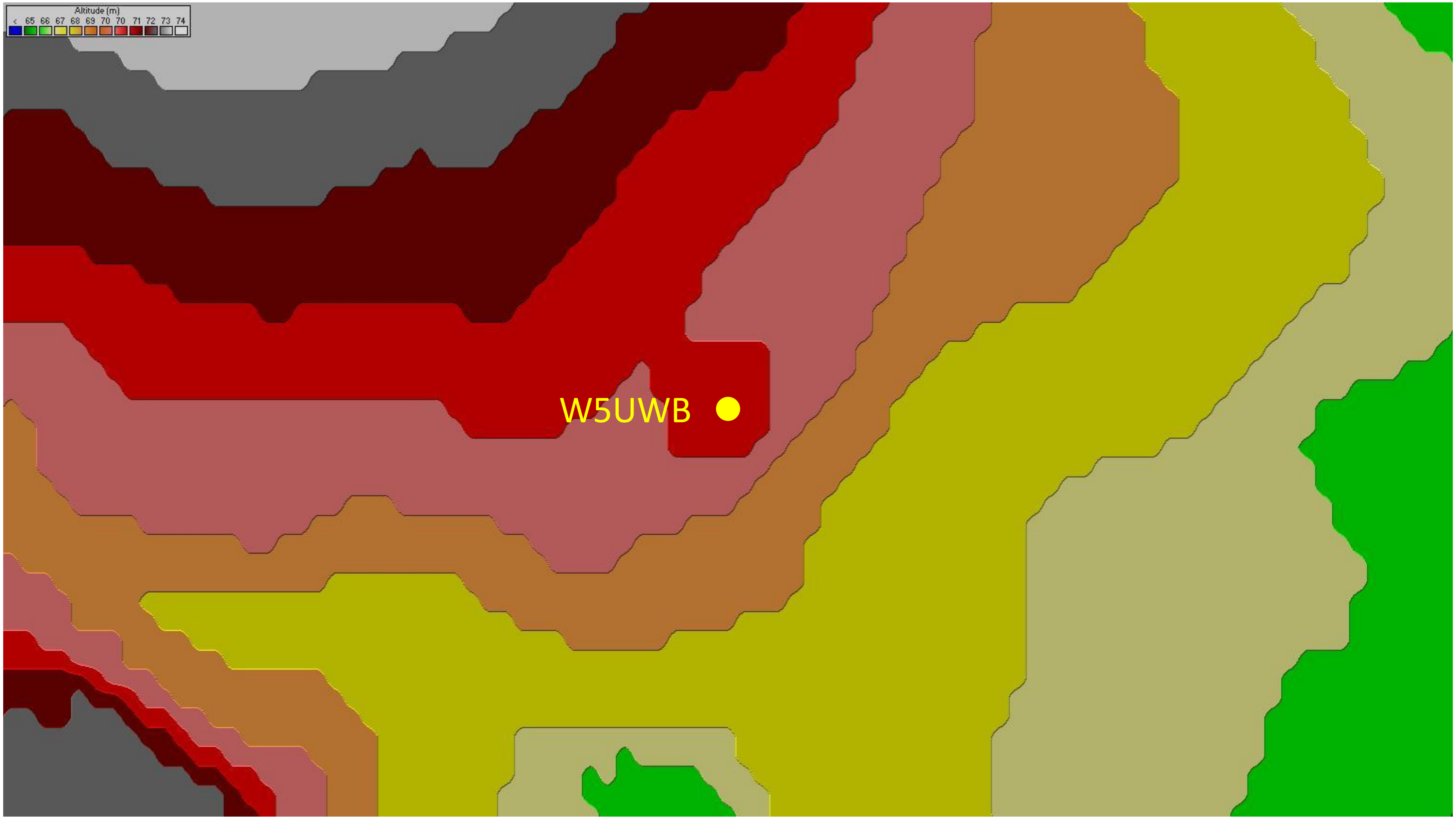
- - - Distance where max. of 1st lobe builds

Picture width*height [km] : 2.3*1.3



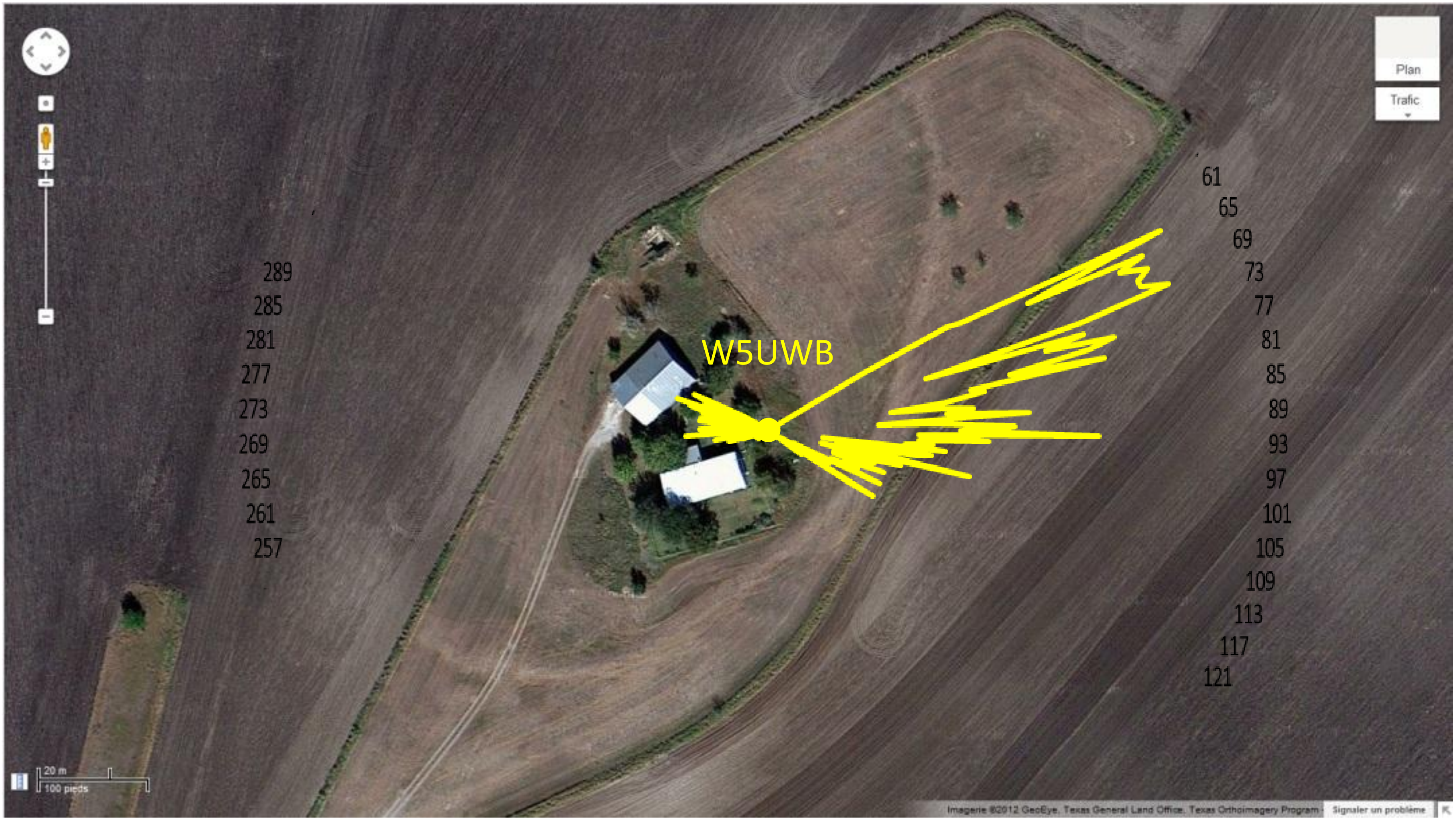
Case Studies – W5UWB – Relief

Altitude span [m] : 65 ➔ 75
Picture width*height [km] : 2.3*1.3

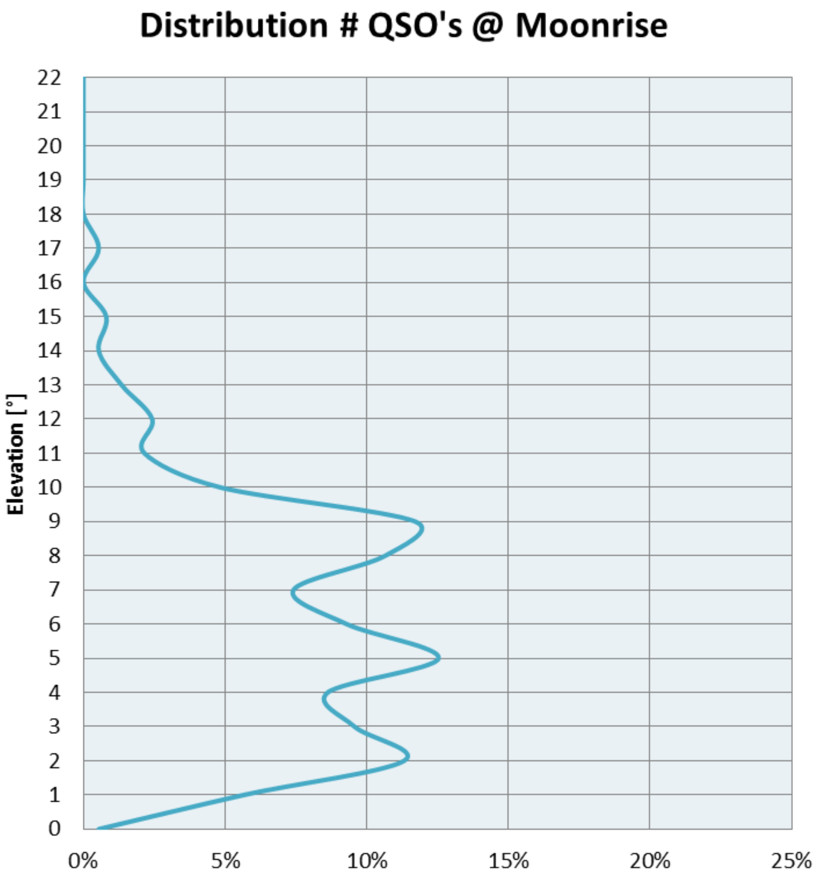


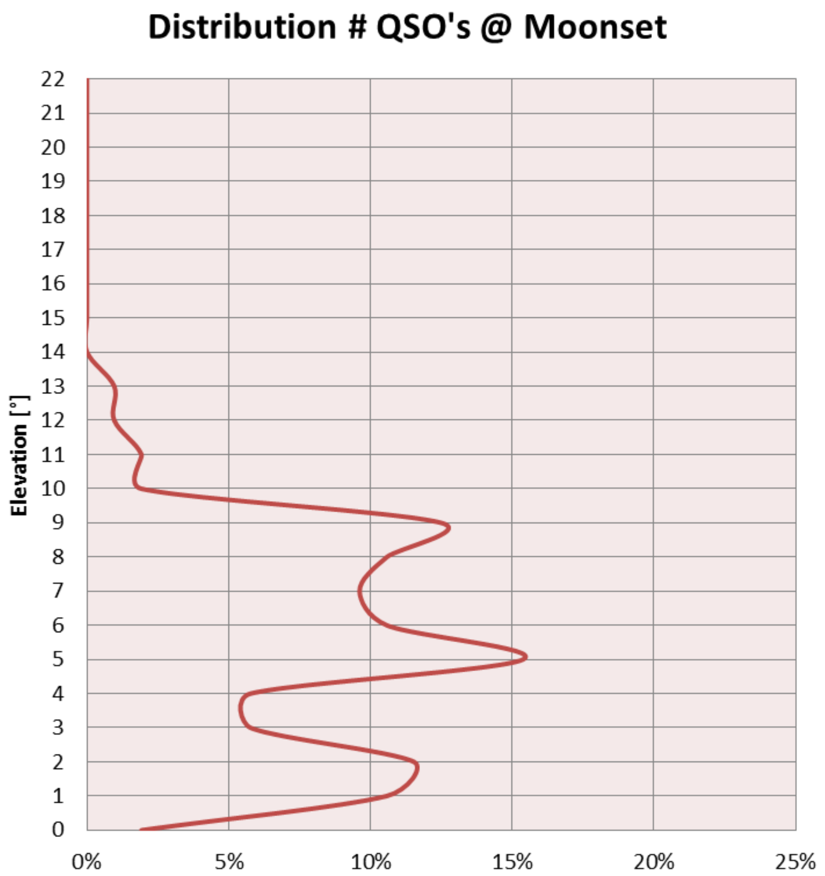
Case Studies – W5UWB – Relative # QSO's vs Azimuth

Picture width*height [m] : 570*320



Case Studies – W5UWB – Distribution of EME QSO's vs Elevation





- Shape not exactly the same but maximum occurring at **same elevation angles** for **both** Moonset and Moonrise.
- Both 5λ & 8λ antennas taken into account on the same graphs ; 75% of the data coming from the 8λ.

Case Studies – W5UWB – Antenna & Summary

- Very **high gain** 16m long antenna ➔ narrow free space vertical plane (H-plane) radiation pattern ➔ very **limited amount** of QSO's above 10° of moon elevation.
- Very **flat** and **un-cluttered** ground over a wide area all around. ➔ **very good Ground Gain** assumed.

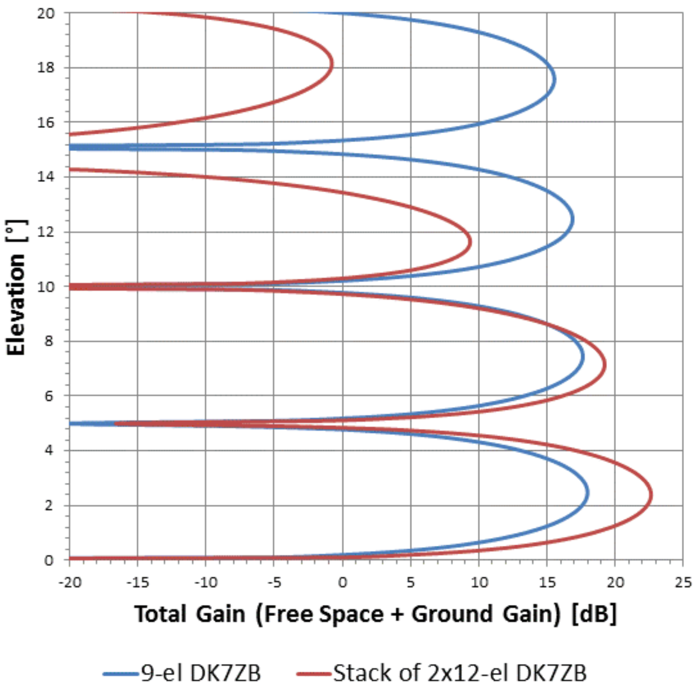
- Effective elevation pattern **matching** with theoretical simulations [2] ➔ 1.7°, 5.0°, 8.3° & 11.6°.
- Despite the assumed good Ground Gain all around, there are **much less** QSO's made at Moonset. This is due to fact there are **less** QSO opportunities from EL17AX in this direction (great deal of Pacific Ocean).
- Likely high amount of the Ground Gain **not reflected** in the **depth** of the nulls on the graphs (deep nulls = high Ground Gain). Probably due to the time spreading in the logging of QSO's and to the fact many QSO's are **spread** amongst **two consecutive** elevation lobes.

Conclusion (1/2)

- Depending on what it is used for, placing an antenna (system) **as high as possible** up in the air is **not always** an absolute requirement. For **EME** operation without elevation, 10m agl seems a **good trade-off** (width of the lobes in elevation vs amount of lobes vs surface onto which lobes build).
- **Flat** and **un-cluttered** (building and vegetation) ground (tilted or not) over a somehow **wide** area all around the antenna (system) is of **prime importance**. An antenna overlooking the obstacles all around is necessary but not sufficient to achieve Ground Gain enhancement.
- In average, the ground offers **less gain** to the **vertical** (V) polarization. Vertical polarization lobes (max.) can develop in horizontal (H) polarization nulls. This makes one more **advantage of using H-V** polarized antenna (system).
- At **shallow grazing** angles, the nature of the ground (good or poor reflector) is **not important**.
- Performing measurements according to the method described here (using the sun noise) will easily highlight one's Ground Gain elevation **lobes geometry**. Regarding the **magnitude** of the lobes, the accuracy is **questionable**.

Conclusion (2/2)

- If conditions are met, Ground Gain enhancement is definitely very **applicable** on 6, 4 and 2m bands. The **2m** band seems to be the **optimum** one to assess its geometry and magnitude through **measurements** (more noise and less RSF at lower frequencies). No investigation conducted so far here on the 70cm band.
- Having Ground Gain is definitely of some benefit for the **terrestrial propagation modes** too, as depicted below.



Comparison of a 9-el DK7ZB (12 dBd free space) with a stack of 2x12-el DK7ZB (17 dBd free space), both at 12m agl over a “good” ground.
The stack will **outperform** the single antenna by 5 dB in the 1st lobe, 2 dB in the 2nd but will be **worst** respectively by 7.5 and 16 dB in the 3rd and 4th lobes !
This could be of **high added value** in Meteor-Scatter, Es, Aurora and sometimes Tropo.

References

- [1] : “Ground Gain in Theory and Practice”, DUBUS 3/2011, page 59, by Gaëtan Horlin, ON4KHG
- [2] : Ground Gain Geometry and Magnitude Calculator File.zip, http://www.on4khg.be/EME_Gr_Gain.html
- [3] : http://www.swpc.noaa.gov/ftpdir/lists/radio/rad.txt , http://www.dxsummit.fi
- [4] : http://www.vk3um.com/software.html
- [5] : “Performance evaluation for EME-systems”, DUBUS 3/1992, by Rainer Bertelsmeier, DJ9BV and Patrick Magnin, F6HYE, http://dpmc.unige.ch/dubus/9203-3.pdf
- [6] : http://www.qsl.net/dl4yhf/spectra1.html
- [7] : Ground Gain Sun Noise Measurement Processing file.zip, http://www.on4khg.be/EME_Gr_Gain.html
- [8] : Ground Gain Measurement Procedure, http://www.on4khg.be/Ground Gain Measurement Procedure v1-0.pdf
- [9] : DUBUS 2/2012, page 107